X PLANES

No: 6

Peter E. Davies

BELL X-2

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SERIES EDITOR TONY HOLMES

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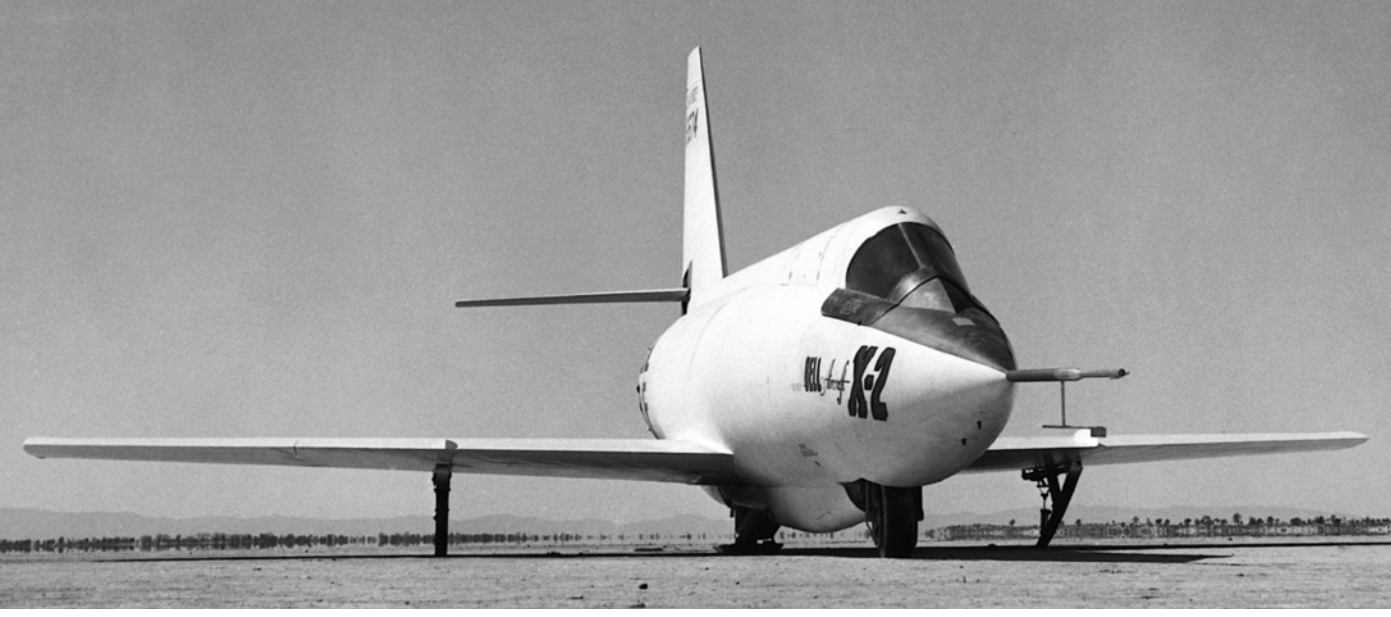


CHAPTER ONE

INTRODUCTION

X-2 46-674 is seen here fitted with "whisker" skids, together with a 12in main skid plate. The nose-gear door, jettisoned when the gear dropped into landing position, was usually considered disposable, and was sometimes left unpainted. The canopy had a reinforcing metal strip added to its leading edge before the maximum speed phase of the flights began on May 11, 1956. (AFFTC via T. Panopalis)

X-plane pilot Bob Champine commented, "There was a lot of spookiness about those research airplanes. There was a different way of flying the research craft and they were quite awesome for those days." When Champine joined the National Advisory Committee for Aeronautics (NACA) test-flying team he replaced Howard Lilly, who had been killed in the straight-winged, jet-powered Douglas D-558-I Skystreak – the first NACA pilot to be lost. NACA had to look to younger pilots to take over as there was some reluctance among the experienced, married aircrew. Champine signed up and flew the Bell L-39, which flight-tested the wing for the second, swept-wing Douglas D-558-II and the Mach 3 Bell X-2. He also made 13 flights in NACA's Bell rocket-powered XS-1, the first aircraft to fly at supersonic speed.

The XS-1 (see Osprey X-Planes No. 1 – *Bell X-1* for further details) had been proposed in 1943 as the first purpose-built US research aircraft, designed to investigate transonic and supersonic flight and provide data for the development of a new generation of high-speed combat aircraft. Its accelerated design and construction in 1945 had been prompted by concern over the problem of compressibility, the phenomenon that caused aircraft to lose control and sometimes disintegrate as they approached high subsonic speeds. Its genesis was also facilitated by supersonic research in wartime Germany and prompted by the appearance in 1944 of Luftwaffe jet- and rocket-powered combat aircraft that seemed to be far superior to anything in US service. Supersonic research in Britain was also in advance of the American effort, and Maj Gen Henry H. "Hap" Arnold arranged for

much of the available British data to be shipped to the USA. In 1941 he also negotiated for British Whittle jet engines to be used in America's first jet fighter, the Bell XP-59A.

The design of a series of aircraft for research purposes rather than as prototypes for combat aircraft was an innovation in American policy. The XS-1's instigator, Robert J. Woods, had hoped that his company's design would eventually lead to production of military versions. However, its small size and very limited endurance (less than five minutes of powered flight after a lengthy and complex ascent to launch altitude under a Boeing B-29 carrier aircraft) made it suitable only for rapid acceleration to supersonic speeds, acquiring as much information as possible for its 500lb of recording instrumentation. It then glided back to a 140mph "dead-stick" landing. Versions of the XS-1 (re-designated X-1 after 1947) not only broke the "sound barrier" for the first time but went on to achieve a record speed of Mach 2.44 and altitudes in excess of 90,000ft in a flight test program that ran from January 1946 to November 1958.

While the XS-1 design process was underway at the end of 1944, the USAAF was already planning flight research at much higher speeds. Bell, therefore, began to study a swept-wing version, having decided to use more conventional, but very thin, straight wings for the XS-1. The revised machine would explore higher supersonic speeds, where kinetic heating due to aerodynamic friction could cause damaging over-heating of aircraft surfaces. At its intended speed of Mach 3 (at a time when the fastest existing aircraft had barely exceeded 500mph), this type of heating would be experienced for the first time.

Data on wing sweep was becoming available through American and captured German data as 1945 progressed, and it appeared to offer the best route to much higher speeds. The USAAF was also anxious

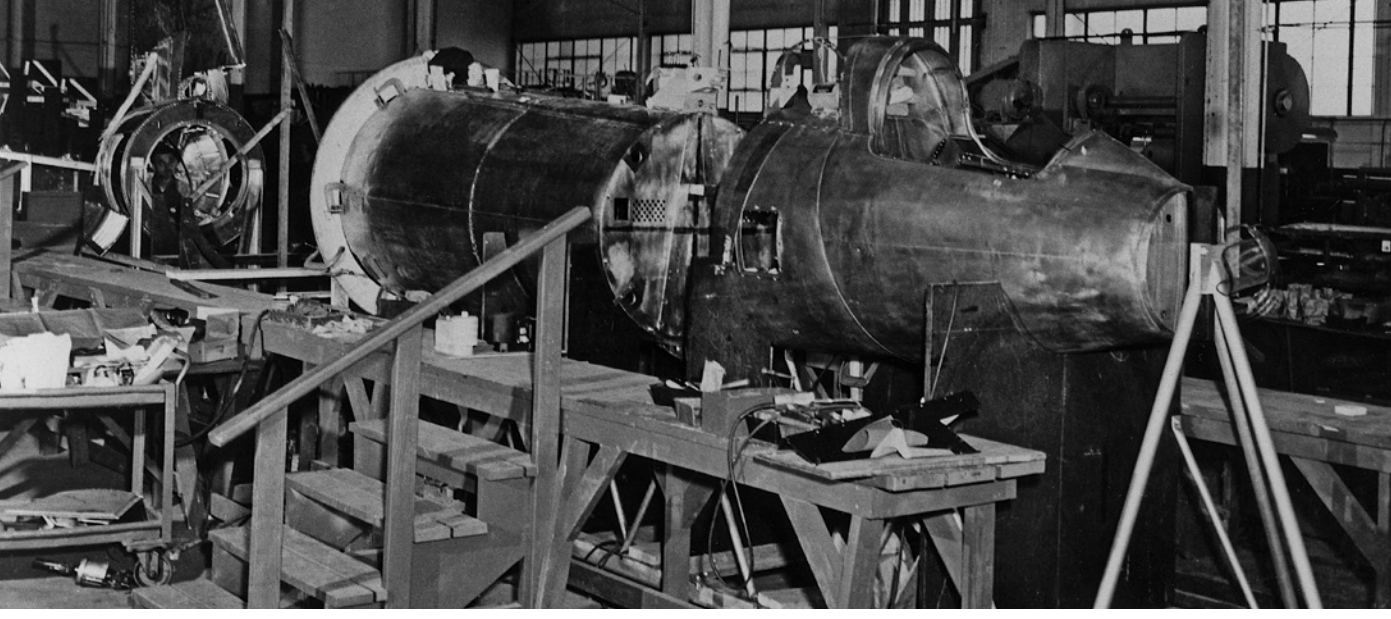
The Bell L-39-1 testing the swept-wing concept for the X-2. The L-39-2 had a wing that more closely resembled the X-2's.

to make up for what it saw as lost ground in that area. By October it became apparent that a totally new design would actually be required, and on December 14 representatives of Bell, the USAAF and NACA signed contracts for the development of two swept-wing Bell XS-2 (later, X-2) research aircraft.

It was the beginning of one of the most glorious, but tragic periods in the X-plane program. Both X-2s were lost in horrifying accidents, costing the lives of their pilots and a crew-member of the carrier aircraft. In a flight test program lasting from July 1951 to September 1956 only 20 X-2 flights were made, 13 of them powered and the rest as "glide" flights. Delays and accidents protracted the project to the point where it risked cancelation, but the X-2 contributed vital knowledge on aircraft stability at high speeds, on the innovative use of advanced heat-resistant alloys in airframe construction and on the "thermal thicket" above Mach 2.5, where high surface temperatures were experienced. It also began to introduce the fly-by-wire control system, and it demonstrated the effectiveness of swept wings at very high speeds. More spectacularly, it made "Pete" Everest "the fastest man alive" when he flew it to Mach 2.87 (1,900mph) in 1956, and on the X-2's final flight in September 1956, it became the first aircraft to exceed Mach 3. Two weeks previously it became the first manned aircraft to fly above 100,000ft, attaining an unofficial world record of 126,200ft.

Lt Col Frank Kendall "Pete" Everest, Jr was a test pilot for the USAAF in the 1950s and was dubbed "the fastest man alive" when he flew the X-2 to Mach 2.87 (1,900mph) in 1956.

Although these achievements were somewhat overshadowed in the 1960s by the North American X-15A-2 (see Osprey X-Planes No. 3 – *North American X-15* for further details), which flew at more than twice the X-2's maximum speed and almost three times its best altitude performance, the X-2 contributed significantly towards the structural, control and airborne launch technologies that formed the foundation for hypersonic flight. For Robert J. Woods, co-founder of Bell Aircraft Corporation, the X-15 was a natural progression from the process that began with his first sketch for the XS-1. In 1952 he proposed an aircraft that would fulfill the X-15's role a year before the X-2 made its first powered flight. If the ill-fated X-2 had survived longer and sustained its flight program without delays, it could have contributed even more to that period of unprecedented advancement in aircraft performance.



CHAPTER TWO

SWEEPING CHANGE

The first X-2 being assembled at Bell's factory in 1949. Manufacture of the main components commenced in the spring of that year, with the aim of meeting a November 1 delivery date. In fact, final assembly did not begin until August 1950. The two aircraft were hand-built and required some innovative techniques and materials to meet the stringent performance requirements. (Bell via T. Panopalis)

Although it has now been succeeded by a variety of more complex wing shapes, the swept-back wing was the most common hallmark of the fast jet in the late 1950s and throughout the 1960s. Some designs, notably the Lockheed F-104 Starfighter, used thin, straight wings, while others opted for a delta planform. However, the swept wing was for many designers the best means of delaying the shock waves and consequent drag and loss of lift resulting from the compression of the airstream ahead of the wing at high subsonic speeds.

Although inventors as far back as former British Army officer John Dunne had built swept-wing biplanes from as early as 1905, most of the work on sweep-back for high-speed flight was accomplished in Germany from the early 1930s onwards. The first serious international debate on the means of achieving supersonic speeds took place at Campidoglio, Italy, in September–October 1935 where the Fifth Volta Congress on High Speeds in Aviation (opened by Benito Mussolini) included a visit to the Guidonia Laboratory. The latter, based on a Swiss wind tunnel at Zurich designed by Jakob Ackeret, a friend of the American supersonic flight advocate Theodore von Kármán, would eventually include a tunnel capable of testing models at speeds up to Mach 2.7, with development potential up to Mach 4. Comparable tunnels were unavailable in the USA or Britain until the mid-1950s, despite them being of considerable help in the development of transonic aircraft. The Germans constructed a tunnel in 1941 that operated at Mach 4.4.

Some of the delegates at the Volta Congress were also presented with a paper by the German engineer Dr. Adolf Busemann in which he suggested swept, or "arrow" wings as a way of delaying the increased

drag caused by high-speed shock waves. A few of the attendees picked up on the idea, including host Arturo Crocco, who responded to the paper by sketching out an aircraft that slightly resembled the Bell X-2, but with a propeller. It was generally disregarded since at that time there was no practical means of powering an aircraft to the speeds at which a swept wing would be an advantage.

However, in Germany in 1939 the High-speed Aerodynamics Branch at Gottingen tunnel-tested models with a 45-degree sweep (an angle later used for the North American F-100 Super Sabre) at speeds up to Mach 0.9. The results, indicating reduced drag at transonic speeds, were passed to the Messerschmitt company, while other tests proceeded using a range of sweep angles at speeds up to Mach 1.2. Messerschmitt was soon battling with the effects of compressibility on its Me 262, the first operational jet fighter, and Me 163, the first operational rocket-powered aircraft, although both benefitted from modest wing sweep. Research into more drastic sweep angles led to Focke-Wulf's Ta 183 and the variable-sweep Messerschmitt P.1101 (see Osprey X-Planes No. 4 – *Luftwaffe Emergency Fighters* for further details) – an example of the latter was captured and duly formed the basis for the Bell X-5 in 1951.

The German DFS 346, a swept-wing, rocket-powered glider with a skid undercarriage, was unfinished at war's end. The Russians captured it, completed work on the glider and tested it as the Samolyot 346, dropping the machine from a wing-mounted pylon below a Tupolev Tu-4 (B-29 clone) bomber. Test pilots reported experiencing severe control problems during a brief test program in 1951. On its second powered flight test pilot Wolfgang Ziese exceeded 560mph, but the aircraft soon became unstable and he was forced to use the nose-mounted escape capsule and parachute to safety. DFS designer Felix Kracht had intended the aircraft to reach Mach 2.6 when air-launched from a Dornier Do 217 and flown on reconnaissance missions, relying on a Walter 509B/C two-chamber rocket motor intermittently to maintain speed. The program was abandoned in September 1951.

In England, the Miles Aircraft Company had opted for a thin, straight wing (later echoed very successfully in the Bell X-1) for its M.52, a 1943 jet-powered design that might have achieved 1,000mph. It used a bi-convex wing section, an all-moving tailplane and a jettisonable pilot's cockpit capsule. Details of all these secret innovations were made available to Bell designers in the fall of 1944 after the British government ordered Miles to hand over the relevant research data to a visiting American team. The M.52 was canceled in February 1946 just short of completion, and the absence of a swept wing was cited as a reason for the British government's lack of faith in the project.

Instead, the swept-wing, tail-less de Havilland DH 108 was allowed to continue in development. Despite the loss of two of the three prototypes, the DH 108 became the first British aircraft to fly supersonically, achieving Mach 1.04 on March 1, 1949 in a near-vertical dive during which pilot John Derry reported that, "There was absolutely no control at this point, and all the lateral control, which had been effective after all else, had now disappeared." It was a phenomenon that Bell X-plane pilots would also encounter.

Captured German data was also used to design Russia's Mikoyan-Gurevich MiG-8 "pusher" with a canard and swept-back wings in 1945, and then to better effect in the MiG-15 in 1948, with swept-back wings and a British Nene jet engine. Its appearance in combat during the Korean War and its clear superiority over Allied straight-winged fighters was a major incentive in the development of a new breed of US jets in the 1950s. American scientists also combed through the German research facilities in Operation *Paperclip* as the war ended. Boeing's George S. Schairer was among them, and he recommended that his company should follow up the German initiatives, leading in due course to the B-47 Stratojet and B-52 Stratofortress bombers, which began life as straight-wing designs. A team from the Douglas Aircraft Corporation also visited Germany in 1945 as part of the Naval Technical Mission, and its findings later added a swept-wing version to the US Navy's D-558 high-speed research aircraft project which ran parallel to the USAAF/NACA Bell X-1.

America's own swept-wing research was led independently by Robert T. Jones at NACA. Without the benefit of German data or the theories of Dr. Adolf Busemann, Jones discovered wing sweep while working on thin, flat wing designs (slender wing theory). He discussed his ideas with Ezra Kotcher, a senior member of the USAAF's Wright Field Engineering School who had been exploring the aerodynamics of supersonic flight since the late 1930s. Kotcher in turn talked to Theodore von Kármán, head of the USAAF's influential Scientific Advisory Group in mid-1944. The previous year, von Kármán had assured Gen Frank Carroll, chief of the USAAF's Engineering Division at Wright Field, that his decades of research showed him that it was possible to build an aircraft capable of 1,000mph.

The first X-2, 46-675, was given an unofficial roll-out on November 11, 1950. Its unpainted surface shows the variety of temperature-resistant metals required in its manufacture. Following eight months of ground tests, the aircraft was used for the initial unpowered flights in 1951 because 46-674 was intended as the recipient of the first XLR-25 rocket engine. (Bell via T. Panopalis)

In April 1945 Jones reported on his findings. Many at NACA were critical of his assertions, but he was supported in May by a second report from Robert Gilruth which showed that free-flight models with thin wings and sweep-back demonstrated a marked reduction in high-speed drag. Useful data also came from a 1940 paper by Antonio Ferri entitled "Experimental Results with Airfoils Tested in the High-speed Tunnel at Guidonia," later re-published by NACA. It explored the use of bi-convex wing sections at speeds up to Mach 2.3.

Although the USAAF expressed an increasing interest in the swept wing, it elected to support NACA in selecting a straight wing for the Bell XS-1. This was partly because it sought more data on straight wings for the development of its first operational jet fighter, the Lockheed P-80 Shooting Star, and also because the swept wing had not yet been tested experimentally in the USA. However, in late 1944, Wright Field's interest led to a Bell proposal, the Model 37D, which was a swept-wing derivative of its XS-1 using a 40-degrees swept wing in both forward and rearward sweep positions. Wind tunnel tests showed that the combination of the XS-1 fuselage and a new wing did not work well without substantial redesign of the former. A completely new project therefore began – the Model 52.

XS-2 BEGINS

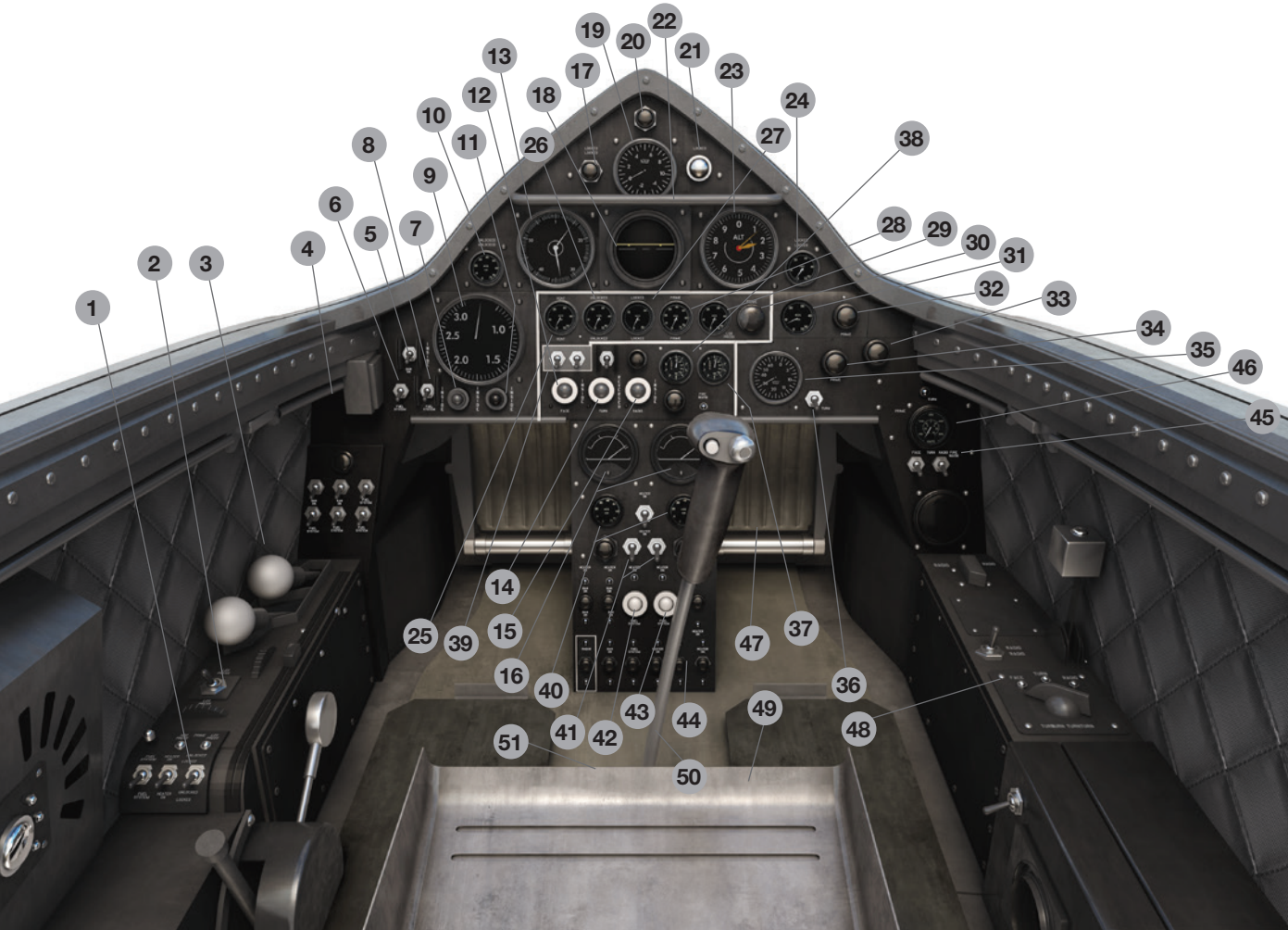
Preliminary contracts were signed on December 14, 1945 under Project MX-743, or XS-2, only nine months after signature of the contracts for the XS-1 and almost two years before Capt Chuck Yeager would show that supersonic flight was possible in that aircraft. A team led by Bell's chief engineer Robert M. Stanley, and which included Stanley W. Smith, Paul Emmons and test pilot Jack Woolams – all of whom were also involved with the XS-1 project (MX-524) – quickly started work on MX-743.

Stanley W. Smith soon moved from the XS-1 to take charge of the XS-2 project, and he was replaced on the XS-1 by Richard H. Frost. Jack Woolams made the XS-1's first flight on January 25, 1946 and he continued its test flight program until March 6 at Pinecastle AAF, Florida, where all ten of the initial contractor's unpowered flights took place. He had been involved in discussions concerning the XS-2 during 1945, and he would also have flown it had he not been killed in a "hot-rodded" Bell P-39 Airacobra while preparing for the Thompson Trophy air race in August 1946. Emmons was given responsibility for the overall shape of the XS-2, and the team also included Bell engineers Jack Strickland, Harold Hawkins and Charles Fay. They were tasked with building an aircraft that would fly far faster and higher than any previous machine, using a new rocket powerplant and construction techniques and metals that were largely untried. The XS-2 was discussed at length during a three-day conference held at Bell's Niagara Falls facility from January 3, 1946 while USAAF representatives inspected the first XS-1.

As the swept wing was to be the XS-2's primary aerodynamic feature, the concept was extensively tested by "Tex" Johnston during the

BELL X-2 COCKPIT

1. Power control switches
2. Aileron trim
3. Power controls
4. Battery switch
5. Flap control
6. Battery selector switch
7. Instrumentation calibration switch
8. Stabilizer sensitivity switch
9. Mach meter
10. Flap position indicator
11. Galvanometer zero switch
12. Gas generator re-set
13. Airspeed indicator
14. 5,000lb thrust chamber re-set
15. 10,000lb thrust chamber re-set
16. Voltmeters for batteries Nos. 1 and 2
17. Landing gear down light
18. J-8 attitude gyro indicator
19. Accelerometer
20. Turbine “off” light
21. Data light
22. “Grab” bar
23. Altimeter
24. Stabilizer position indicator
25. Lox tank pressure indicator
26. Fuel tank pressure indicator
27. Propellant line pressure indicator
28. Chamber pressure indicator
29. Nitrogen pressure indicator
30. Galvanometer zero switch
31. Stabilizer sensitivity indicator
32. Oxygen warning light
33. Instrument compartment overheat warning light
34. Launch light
35. Cabin air pressure indicator
36. Launch signal switch
37. Fuel remaining indicator
38. Lox remaining indicator
39. Lox and fuel tank pressure/vent switches
40. Hydraulic systems’ 1 and 2 pressure indicators
41. Hydraulic systems’ pump switches and warning lights
42. De-fogging control
43. Emergency canopy release
44. Circuit breakers
45. Radio switch
46. Cabin differential pressure gauge
47. Rudder pedals
48. Communications controls
49. Pilot’s seat
50. Control column
51. Cabin jettison T-handle (under edge of seat)

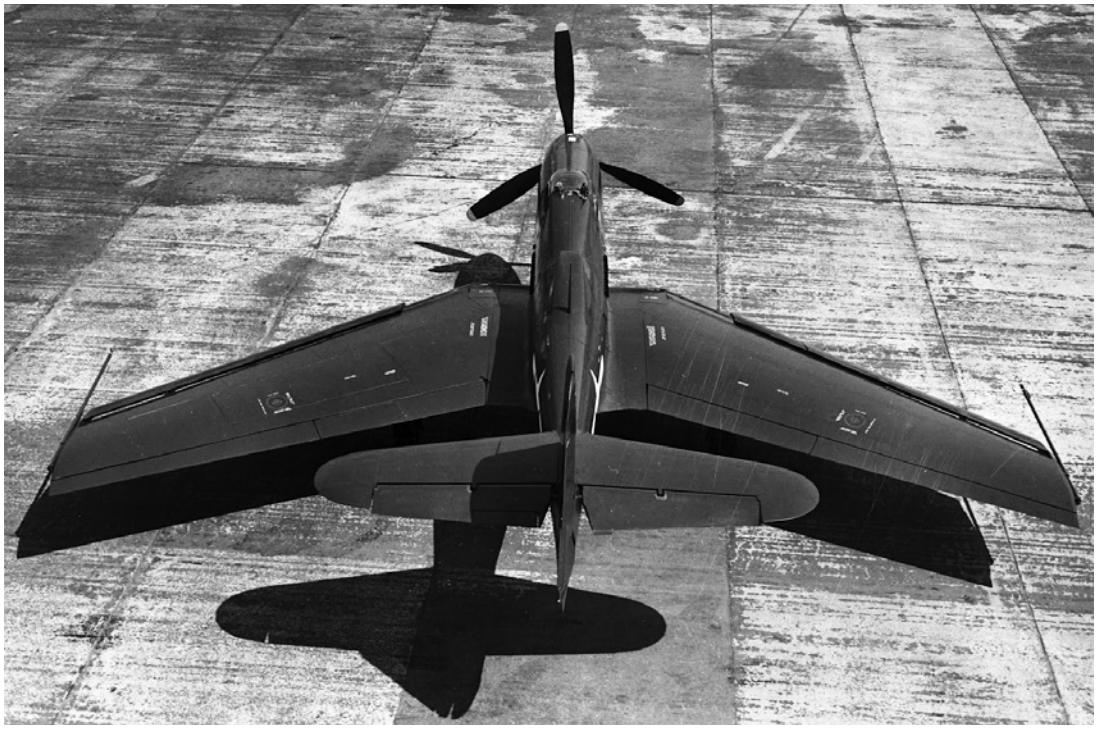


summer of 1946 using converted P-39C Airacobras L-39-1 and L-39-2 (registered as BuNos 90060 and 90061, respectively – they were also known as XP-63Ns) that Stan Smith had organized. Under a US Navy contract, hence their US Navy Bureau of Aeronautics serial numbers, these propeller-driven fighters received 35-degrees swept wings adapted from surplus P-39E wing panels that were fitted with adjustable leading-edge slats. They also had extended fuselages to restore the center of lift to a controllable position and ventral fins to aid stability.

Since their main function was to explore the low-speed handling of swept wings, only the nose landing gear was retractable. The first aircraft was intended to produce data for the US Navy's Douglas D-558-II Skyrocket supersonic aircraft, and it was later shipped to NACA at Langley, where it produced very useful wind tunnel results. L-39-2, operated by Bell under a USAAF contract, was given a sharp-edged wooden wing leading edge to provide the bi-convex aerofoil section that would be employed on the XS-2, soon re-designated X-2. Professor Jakob Ackeret, the Swiss wind tunnel pioneer, had published work on bi-convex aerofoils in 1932, advocating them for supersonic flight. Bell intended to put those theories to the test, and flights by Jack Woolams from July 20 showed that the wing handled well at low speeds.

STRUCTURE AND CONTROL

Emmons experimented with placement of the X-2's wing, trying it as a shoulder-mounted high wing combined with a large ventral fin and briefly trialing a forward-swept variant (using an X-1 model fuselage)



Bell's converted L-39-1 or XP-63N, procured to test the feasibility of wings swept at 35 degrees. (Bell)

and a variable-sweep wing, as suggested by NACA's Charles Donlan. The latter proposal was disregarded due to a lack of research data, although the company did explore the idea further with two X-5 jet aircraft. Although they proved the concept to some extent, these aircraft were deeply unpopular with some of their pilots due to vicious stall characteristics.

Eventually Emmons' team settled for a low-mounted wing spanning 32ft, with three degrees of dihedral and 40 degrees of sweep-back, together with the innovative bi-convex aerofoil tested on the Bell L-39. The all-moving, powered horizontal stabilizer was positioned at the base of the vertical tail fin. It had the same sweep angle as the wing and a thinner aerofoil section to give a higher critical Mach number than the wing. The same principle had been applied to the X-1 airframe, thus ensuring that the airflow (and therefore the transonic compressibility factors) over the two surfaces would differ so that they would not lose lift at the same speed. Like the X-1's stabilizer, it could be rapidly adjusted, in this case with its leading edge angled up by a maximum of seven degrees or down by ten degrees to counteract trim changes as the aircraft approached supersonic speed.

To assist further with control, the large, flat, powered ailerons had blunt trailing edges, half the thickness of the aileron at their leading edge. This became necessary after wind tunnel tests showed that the ailerons lost effectiveness in the transonic speed range (as the X-1's ailerons had also demonstrated) and suffered from control reversal, giving the opposite effect to the intended pilot input. There were also small wing fences to improve airflow.

All the flying surfaces were skinned with stainless steel, tapered from root to tip. It was known that aluminum would soften and distort at temperatures above 350 degrees F, and skin temperatures of at least 630 degrees F could be expected at Mach 3. With an internal temperature in the liquid oxygen (lox) tank of minus 297 degrees F, there was clearly a huge challenge ahead in finding a metal that would retain its strength with such a massive temperature differential. By 1949 manufacturing techniques had been developed to work with this heat-resistant metal, and with the K-Monel (nickel/copper alloy) that could then be used for much of the fuselage structure. It had twice the strength of steel and slightly greater weight, but it was heat resistant up to 750 degrees F.

Developed by Ambrose Monell of the International Nickel Company in 1906, the K-Monel alloy of nickel and copper not only cost more than five times as much as conventional alloys, it had never been used in aircraft construction. It was also very resistant to corrosion that would be caused by the fuel and oxidizer used in rocket motors, and it could be spot-welded or brazed for airframe construction. The use of such specialized metals marked a real break with conventional aircraft structural methods. For Bell, the extra cost and evolution of new metal-working techniques that took the company two years to perfect was vital if the X-2 was to explore the "heat barrier."

Lacking wind tunnel data in 1945 on the stresses that the XS-1's aluminum airframe might encounter at supersonic speeds, Bell designers built (or over-built) it to survive aerodynamic stresses of 18g – more than twice the factor assumed for contemporary combat

X-2 46-675 shows off its clean, purposeful lines as it sits on its hydraulic dolly in 1952. Internally, it was far more complex. The aircraft was extensively instrumented with strain gauges and other sensors to measure its performance, acceleration and maneuvering, control positions, angle of attack and sideslip. Connecting all the sensors required 4,000ft of telemetry cabling. (NASA Dryden Flight Research Center Archives)

aircraft. For the X-2, with far stronger metals, an aerodynamic load factor of 8g at gross weight was agreed, plus a further safety factor of 1.5g, guaranteeing that there would be no structural failure during acceleration up to 12g. This was closer to the limits for production combat aircraft. Particular emphasis was placed upon the strength of the tailplane, which was built to withstand a load twice that of the aircraft's design weight in an 8g pull-up. This was done in recognition of the fact that tailplane failure had been a principal factor in the loss of a number of other aircraft at high subsonic speeds.

The flying controls of the XS-1 were un-boosted, although the all-moving horizontal tail had electrical actuators to alter its trim. The system was similar to that fitted in the North American F-86 Sabre. It was an easy aircraft to fly in most situations, but it did require considerable pilot input to wrestle with the controls when the machine encountered instability at high Mach. At 76,000ft (where the air has only four percent of its sea level density) and Mach 2.3, the X-1A completely lost stability during a December 1953 flight, entering wild 11g maneuvers that almost cost the life of pilot Capt Chuck Yeager. For the X-2 its designers wanted a fully electrically controlled system, with screw-jack actuators for the horizontal stabilizer and ailerons to give the pilot sufficient control authority. This had to be accomplished without a power source driven by the engine – the usual arrangement in jet- or piston-engined aircraft – because rocket power would only be available for part of the flight. Electrical power, lasting for 30 minutes, was provided instead by a 300lb, 28-volt nickel-cadmium battery, although this was later replaced by two conventional lead-acid batteries.

Lighter than a hydraulic control system, the electrical method developed by the Eclipse-Pioneer Division of the Bendix Corporation was operated by the pilot via a double-jointed control column equipped with artificial feel. It was installed in the first X-2, but ground tests showed that the electrical control signals to the flying surface actuators could not keep up with the pilot's control inputs. This caused a backlog of signals which the system struggled to match, eventually operating the ailerons and tailplane at such high frequency that they were merely

vibrating without controlling the aircraft. Clearly the idea was ahead of the available technology, and after lengthy tests the system was replaced by a normal hydraulic arrangement before the aircraft's first powered flight.

Electrical trimming of the horizontal stabilizer was similar to the XS-1's. In fact, a temporary set-up with manual control linkages and cables had to be installed to enable the early glide flights to take place. Hydraulic controls were then fitted later in the program, although the rudder used a conventional mechanical linkage system, backed up by a pilot-operated hydraulic lock that fixed it in the neutral position for high-speed flight, leaving directional control to the ailerons only. Allowing the rudder to move freely at supersonic speeds could have admitted shock-induced vibrations through to the pilot's controls. Hydraulic rudder actuation linked to the movement of the ailerons to improve coordinated turns was not thought possible, partly as a weight-saver. Dual hydraulic systems operated at 1,000psi, and failure of one system triggered an automatic transfer of 2,000lb of hydraulic pressure to the other. As an alternative to the "manual" system, overall pressure could be increased to 2,000psi using the "power control" switch on the left side of the cockpit if greater control force was required at higher speeds. Bell called this "unusual conditions," suggesting loss of normal control due to roll coupling or similar phenomena.

Artificial feel (a simulated sense of control force) was provided with the power control system engaged so as to compensate for loss of the normal control force sensations for the pilot. The control column was pivoted at two points near the pilot's stick grip, one pivot acting in the vertical (pitch control) plane and the other for lateral control. Stick forces were exerted against a C-spring at each pivot point, and signals were generated there by an autosyn (a remote-indicating instrument) that automatically connected with the electrical servo actuators of the flying control surfaces via a magnetic amplifier. In an emergency one servo could power both ailerons. The pilot had a dial to increase or decrease the stick pressure and, therefore, the sensitivity of the autosyns, thereby varying the amount of movement of the control surfaces relative to the stick pressure he exerted. However, even this arrangement would prove inadequate for maintaining stability at the high speeds that the aircraft would reach. No suitable stability augmentation system was available at the time, and its absence would be felt in the latter stages of the test program.

Leading-edge and trailing-edge flaps, deflecting 45 degrees down, were included for low-speed flight and landing. A single switch activated motor-driven actuators that lowered both sets simultaneously as they were mechanically interconnected. The leading-edge set was fixed in the "up" position as it was found to be unnecessary early in the test program.

FROZEN FLYING

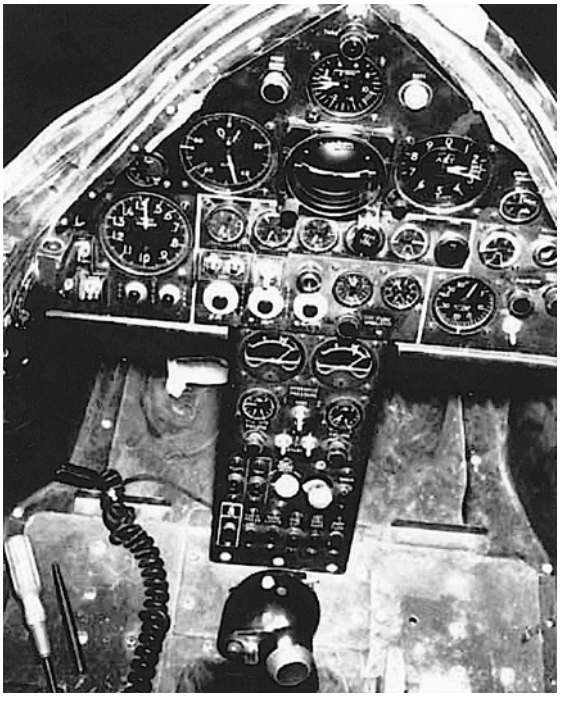
The pilot's tiny cabin area was covered by a hatch and V-shaped tempered glass windshield reminiscent of the types chosen for the X-1E and X-15. It was completely removed for access to the cockpit

X-2 46-675 with its FS 17925 gloss white paint and stencil markings, but still lacking an engine. (AFFTC via T. Panopalis)

by unlatching it from the outside, or by using the pilot's internal latch control on the right cockpit wall. With one man stationed each side of the nose, the hatch cover was lifted off and placed on the ground ahead of the aircraft to allow the pilot to step out of his cockpit. An emergency release cable was also included inside a door on the nose-cone. Pressurization for the cabin came from an air tank in the nose-wheel well, maintaining a constant 2.75psi cabin pressure.

As the X-2 would sustain high skin temperatures during its supersonic flights, the cabin had to be insulated with glass wool to protect the pilot. The tempered plate glass used for the cockpit transparencies could withstand 1,000 degrees F, and it was tinted to filter out infra-red light. Several flights in the earlier X-1s had been put at some risk when condensation from the pilot's exhalations had fogged the windshield, preventing forward vision. The X-2 had a dehydrating canister behind the seat head-rest, connected to the pilot's oxygen mask, to prevent this hazard. An improved de-icing system using isopropyl alcohol from a tank sited just above the cabin recovery parachute was also included. The pilot's oxygen supply came from two tanks situated just behind his cabin, fed through a D-1 regulator to his mask.

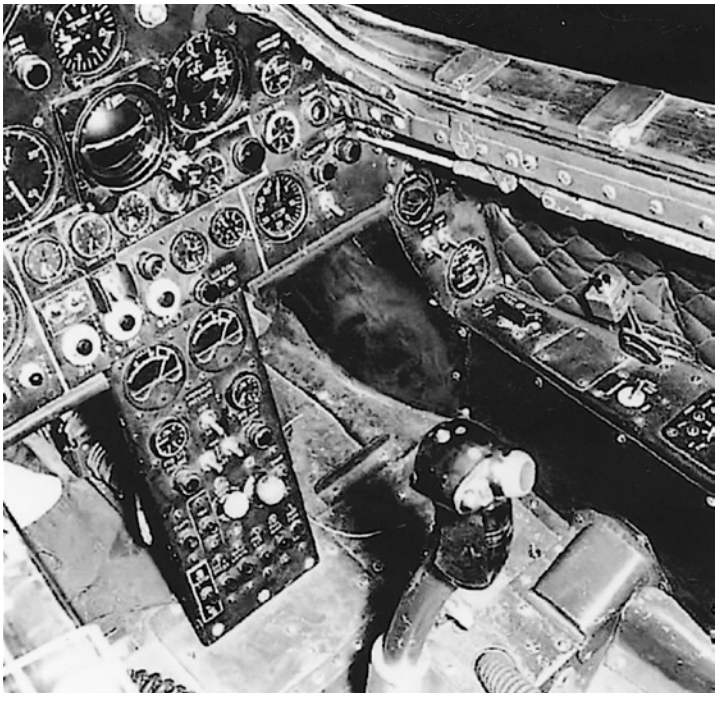
Squeezed into his racing car-like cockpit, the pilot's arms were in contact with the cockpit walls and he was unable to turn either way. His helmet almost touched the windows and he had to use his right hand to reach controls on the left side of the cockpit, and vice versa. The rudimentary seat could not be adjusted, so most pilots had great difficulty in reaching the rudder pedals with any degree of comfort. There was no heating, so pilots relied on layers of heavy clothing, adding to their immobility and discomfort.



The cramped cockpit of the X-2. The main, larger displays include an airspeed indicator (left), a J-8 attitude gyro (center), which Capt Iven Kincheloe dismissed as being completely inaccurate, and an altimeter. The large Mach meter is situated at the lower left, and above the J-8 are an accelerometer and the vital cabin air pressure indicator (lower right on the main panel). The three light-colored knobs at the base of the main panel are reset buttons for the rocket motor chambers, and above them is a row of pressure indicators for the propellant systems. (Bell)

Another consequence of the cramped cockpit dimensions was the miniaturization of the dials, which were all half their usual standard USAAF dimensions on the Bendix/Magnesyn instrument panels. This was of little help to the pilot, who had to check 127 dials and switches during the pre-flight wait. A possible legacy of NACA's original conservative estimates of the X-2's performance was the fact that the Mach meter was only calibrated to Mach 3 and the altimeter ran out of numbers at 100,000ft. Both figures would be considerably surpassed. The instrument array also included a J-8 attitude gyro, but this was found to be inadequate for the X-2's flight profiles.

When the basic configuration of the X-2 was decided, its aerodynamic viability had to be established by the best possible means. In the absence of suitable high-speed wind tunnel facilities, NACA flew a series of four configuration models, boosted by Deacon free-flight rockets. The 160lb models had scaled-down steel wings and aluminum fuselages, and they were instrumented with six- or twelve-channel telemetry equipment to measure acceleration, angle of attack and pressure on the external surfaces. Test flights continued from May 1950 to December 1953 at speeds up to Mach 1.18.



Bell had reverted to a hydraulic control system, rather than the original Bendix analogue power control system, by the time this photograph was taken. The lower instrument panel includes dials for the battery voltmeters (top), hydraulic pressure gauges, pump switches and circuit breakers (lower section). A very necessary, thick layer of glass wool insulation is visible on the right-hand wall. (Bell)

Engineless X-2 46-675 is test-mated to EB-50A 46-011, which still awaits fitment of the glazed dome for the observation hatch in its fuselage side. Considerable external reinforcement was required to its fuselage as so much had been cut away to house the X-2. The bomber's main wheels are raised on 20-ton hydraulic lifts. The X-2, with the original wingtip skids fitted, is maneuvered under the EB-50A using a special Bell-designed transport dolly that was supplied in the summer of 1950. It had castering front wheel assemblies, with hydraulic pumps to raise them. (Bell via T. Panopalis)

HITCHING A RIDE

The X-2's overall size, like that of the XS-1, was limited by the space available in the carrier aircraft that would be used to transport it to launch altitude. Bell and the USAAF had decided on the use of a converted bomber to haul their XS-1 aloft so that its limited rocket motor endurance, giving about five minutes of powered flight, could be used entirely for acceleration to high speeds in the thinner atmosphere above 20,000ft. For their rival, heavier Douglas D-558-II, the US Navy initially opted for ground takeoff, using jet and then jet plus rocket engines. An accident on the three-mile takeoff run, such as undercarriage failure, would have caused a catastrophic explosion of the rocket and jet fuels, and by the end of 1949 Douglas also opted for an air-launched version and deleted the jet engine in favor of more rocket fuel.

The need to match the rocket aircraft to the "mother ship" Boeing B-29 or B-50 carriers placed clear design limitations on the design of both the X-1 and X-2 airframes in terms of weight and size. Their fuselage lengths were restricted by the amount of fuselage surrounding the bomb-bay of the carrier aircraft that could be cut away without jeopardizing its structural strength. Steel reinforcement beams were required to maintain rigidity, and although the pressure bulkheads in the fore and aft fuselages of the Boeing aircraft had to be kept, areas of the fuselage were removed to accommodate the X-planes' tail units and fuselages. The latter had to be partially fitted inside the bomb-bay so that the pilot could enter the cockpit during the ascent and fuel systems could be topped up in flight. Ground clearance of the suspended load – a matter of inches for both X-planes – was also a factor, as was the carry-through structure of the bombers' wing center section which formed a roof over the bay and limited the amount of recessed space for the "passenger" aircraft.

Fuselage length was therefore limited to 45ft, including the nose probe, for the X-2 (35ft 8in for the second-generation X-1A/B variants), but its extra gross weight of 24,910lb compared with 16,487lb for the heaviest X-1 version necessitated a more powerful carrier than

The X-2 was kept steady in its bomb-bay housing by sway braces against the fuselage sides and between the wings of the two aircraft. A lox boil-off pipe can be seen extending from the bomb-bay, where it was connected to a boil-off valve on the upper left fuselage of the X-2. Pilots experienced a sudden, dazzling burst of sunlight as the X-2 dropped from its two bomb-bay shackles, leaving the interior darkness of the carrier aircraft. (AFFTC)

the B-29A, which had borne most of the X-1s aloft. Surplus EB-50A 46-011, capable of carrying payloads of up to 40,000lb, was therefore converted. Its four 3,500hp Pratt & Whitney R-4360-35 radial engines gave it a significant power boost over the 2,200hp Wright R-3350-23s used in the B-29A. Like the latter, 46-011 retained two of its bomb shackles to hold and release the X-plane, having been used to launch X-1s in the latter part of that program. The EB-50A also had an internal tank to top up the lox as it boiled off, a nitrogen supply to start up the motor's turbopump and an X-2 control panel.

The choice of aerial launching and the nature of the base from which the X-2 would operate had a direct influence on the aircraft's landing gear configuration. Whereas the X-1 series had a conventional undercarriage, and on one occasion Capt Chuck Yeager made a takeoff from the ground to defy US Navy claims that it could not be compared with their ground-launched D-558 before the latter also became air-launched, the X-2 needed only the simplest method of recovery to terra firma. Like the X-1s, it would operate only from the semi-secret USAAF/NACA facility within Edwards AFB, California. The "airfield" was Rogers Dry Lake, a massive 65-square-mile expanse of remote, flat desert land that the USAAF had first used in 1933 as a bombing range. Its surface supported 250psi of aircraft weight, but it offered a smoother, though far dustier landing than a conventional runway – a 15,000ft concrete runway was later added to the site. The dry lake provided miles of landing runs and overshoot space.

Still decorated with Bell's "stork" nose-art, applied for part of the X-1 program, EB-50D 48-096 – the second EB-50 in the X-2 program – has a "captive carry" X-2 snugly fitted in its belly. (AFFTC)

The X-2, in any case, had insufficient internal space for a wheeled main landing gear, as

On the first few glide flights with the later hydraulic flying control system, the controls proved to be overly stiff. Maj Frank "Pete" Everest described it as "binding" or "sludging up," probably because the low temperatures made the hydraulic fluid thicken. This could be alleviated by operating the controls repeatedly during the captive flight phase. Early versions of the protective screens around the X-2's cockpit are installed in the EB-50A shown here. (AFFTC via T. Panopalis)

any available room was needed for instrumentation and propellants. The estimated 100lb weight of a conventional main undercarriage was saved by installing a lightweight retractable skid as the main landing gear, together with a diminutive castering, but non-steerable, nose-wheel gear. The nose-gear was extended by gravity, together with a slight push from the compressed energy in its oleo strut, and the wheel bay was covered by a small door that was jettisoned as the undercarriage extended to save the complexity of a door-operating mechanism. The one-foot wide skid was extended by a single hydraulic strut and pivoted drag link. Landings by the X-2 were, therefore, marked by a long plume of dust as the hardened steel skid, treated with wear-resistant Stellite, ploughed across the desert surface.

Skids were replaced by removing two snap-ring and pin assemblies, and the single strut acted as a shock absorber for landings on slightly uneven ground. The skid was meant to contact the ground first in an almost level final approach and then the nose-wheel would touch down. With the aircraft posed at seven degrees nose down, the pilot then had to attempt to hold a straight course without nose-wheel steering. Small cast steel bumper skids were also initially attached below the wingtips to protect them on landing, but these were removed after the first glide flights. Finally, a small bumper was added under the rear fuselage, and there was some discussion concerning a brake parachute, but the 12-mile, concrete-like landing area at Edwards AFB seemed to make this additional weight unnecessary.

Several variations on this undercarriage arrangement had to be made during the program and, despite its simplicity, it became the most persistent cause of minor accidents and delays in the flight schedule.

CHAPTER THREE

POWER AND PILOT PROTECTION

The blunt trailing edges of 46-674's ailerons, a type tested on the Northrop X-4 to improve stability and pitch control, are visible here. The main skid strut's shallower angle relative to the ground is also obvious, compared with the original, longer arrangement. Flights by the X-1 and X-2 were usually launched within about 40 miles of the dry lake-bed, with the aircraft headed towards Edwards. The rocket fuel ran out as it crossed the base, at which point the pilot would turn back for a landing. The X-2 was always flown within gliding distance of the dry lake. (Bell via T. Panopalis)

The Bell X-1 series was powered by a single Reaction Motors Inc (RMI) XLR-11-RM-3/5 rocket motor with four chambers. It used liquid oxygen and diluted ethyl alcohol fuel, propelled into the rocket chambers by a nitrogen pressurization system. In later versions a steam-powered turbopump, using hydrogen peroxide and manganese dioxide to generate the steam, replaced the nitrogen propulsion. The motor's power was varied simply by firing up combinations of the four chambers, producing a maximum thrust of 6,000lb with all four operating. For the X-2 a new type of motor that could be controlled by a throttle was installed. One of its advantages was that it could be kept running at a selected thrust rather than ignited or shut down, chamber by chamber, to vary its power as the XLR-11 had required. This "on-off" process could cause excess fuel to pool in the chambers, risking an explosion.

Bell originally intended to manufacture the new motor but the contract was given to the Curtiss-Wright Corporation in April 1949 with the intention of saving time and pressure on the relatively small Bell company. The Bell research effort was also impeded by a strike in 1949. Curtiss-Wright had little experience of rocket power, but a team led by C. W. Chillson had conceived a design by August 1947 using research work by Robert Goddard, the pioneer of liquid propellant rocket power in the USA since the 1920s. He had launched free-flight rockets with combustion chambers and liquid propellant tanks in

The second aircraft to fly, 46-674 is manhandled into position under its EB-50D carrier aircraft at Bell's Wheatfield, New York, facility. "Mating" the two aircraft usually took about an hour of slow, careful adjustment while the EB-50 was lowered over its burden and the X-2 was gradually raised into position and secured. (Bell via T. Panopalis)

1926 and devised a turbopump system for rocket motors in 1940. The Chillson team's Curtiss-Wright XLR-25-CW-1 motor also used a pump-driven pressurization system, but had only two chambers. Its throttle control varied the power from 2,500lb thrust to 15,000lb, with 10,000lb maximum from the larger lower chamber and 5,000lb from an upper chamber. Both had surprisingly small exhaust areas compared with jet engines of comparable power. At full power the fuel would last for less than three minutes.

Full development of the motor took almost eight years to complete. After fulfilling its contract for seven engines, Curtiss-Wright would be only too glad to withdraw from the rocket engine business. One major effect of the delays was that most of the research data on swept wings that the X-2 could have yielded was already available from work with the D-558-II by the time that the Bell aircraft's flight program began.

The choice of fuel was predicated by the research that determined the optimum fuel for the XLR-11, which had powered the X-1 and (as the XLR-8) the D-558-II. The enormous, instant thrust of a rocket engine gave clear advantages over turbojet engines, which were of much lower power at that time and slow to accelerate. As jets were dependent upon oxygen, unlike a rocket, they also became very inefficient at the high, airless altitude where high-speed flight was most easily achieved due to the lower atmospheric friction. Rockets actually performed best in a near-vacuum.

Much of the research into rocket engines had been carried out in Germany, and it accelerated as the prospect of Allied victory increased. Ezra Kotcher, who became head of aeronautical research at the USAAF's Wright Field Engineering School, had also explored

the benefits of rocket propulsion extensively and he had proposed a rocket-powered research aircraft in a 1938 study paper. USAAF Chief of Staff Maj Gen Henry H. "Hap" Arnold noted this suggestion, and in 1943 he asked Theodore von Kármán to follow it up as head of a Scientific Advisory Board, requesting that he explore the possibilities of a Mach 1.5 aircraft. The subsequent research eventually led to the specification for the X-1.

Germany flew the world's first liquid-fuel rocket aircraft, the tiny but underpowered Heinkel He 176 V1, in June 1939. Its hydrogen peroxide and methanol fuel drove a Walter HWK R1-203 rocket that could be throttled but provided only 50 seconds of maximum thrust. Although it was canceled soon after its first flight, Willi Messerschmitt continued to develop his own rocket fighter project, the Me 163. Based on work with tail-less aircraft design by Dr Alexander Lippisch at Focke-Wulf and the DFS company in the 1930s, the Me 163 began test flights in 1941 powered by a Walter RII-203 motor that used the extremely hazardous T-Stoff (high-test peroxide) and Z-Stoff (potassium permanganate, a catalyst) or C-Stoff (hydrazine hydrate) as fuel. Known as hypergolic chemicals, these substances ignited on contact with each other, requiring no ignition system. They then produced enough heat to melt most metals and released sufficient energy to drive the Me 163 at speeds that were more than 200mph faster than those achieved by the most advanced Allied fighters of the period.

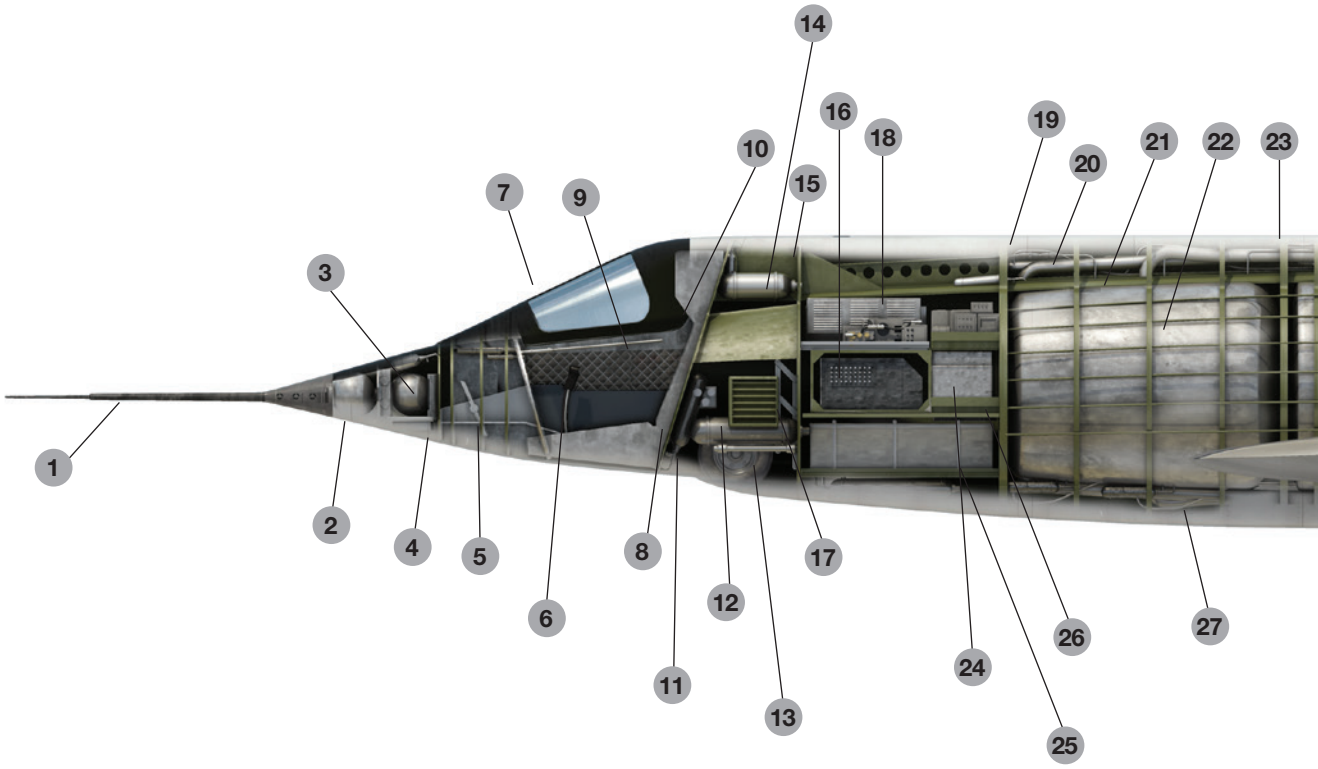
However, the fuel was both toxic and very volatile. Minute contamination of the combustion chamber with Z-Stoff could cause a catastrophic explosion, and exposure to the fuels could cause severe injury or death to air- and groundcrew, who had to wear asbestos suits when handling it. The Me 163 took off from the ground, using a wheeled dolly that was released on lift-off. Like the X-2, the landing gear consisted of a skid, although a tail-wheel was also used. While the small numbers of production Me 163s inflicted relatively little damage on the Allied bomber streams, their psychological impact was considerable – so much so that the idea of a short-ranged, rocket-powered interceptor persisted well into the 1950s.

Bell designers quickly rejected the lethal hypergolic fuels used by the Germans, while the whole idea of rocket power for the X-1 and D-558 was challenged by NACA and the US Navy. They preferred the comparative safety of turbojets, and also pointed out that the requirement to carry a considerable quantity of oxidizer for the fuel was a severe weight penalty. Finding appropriate metals for the motor that could stand temperatures of 4,500 degrees F was also a challenge. However, Kotcher's rocket preference was accepted by April 1944. Its superior power-to-weight ratio, the absence of a drag-inducing air intake and its high performance, which improved at high altitudes, were all persuasive factors, given the availability of a relatively safe fuel.

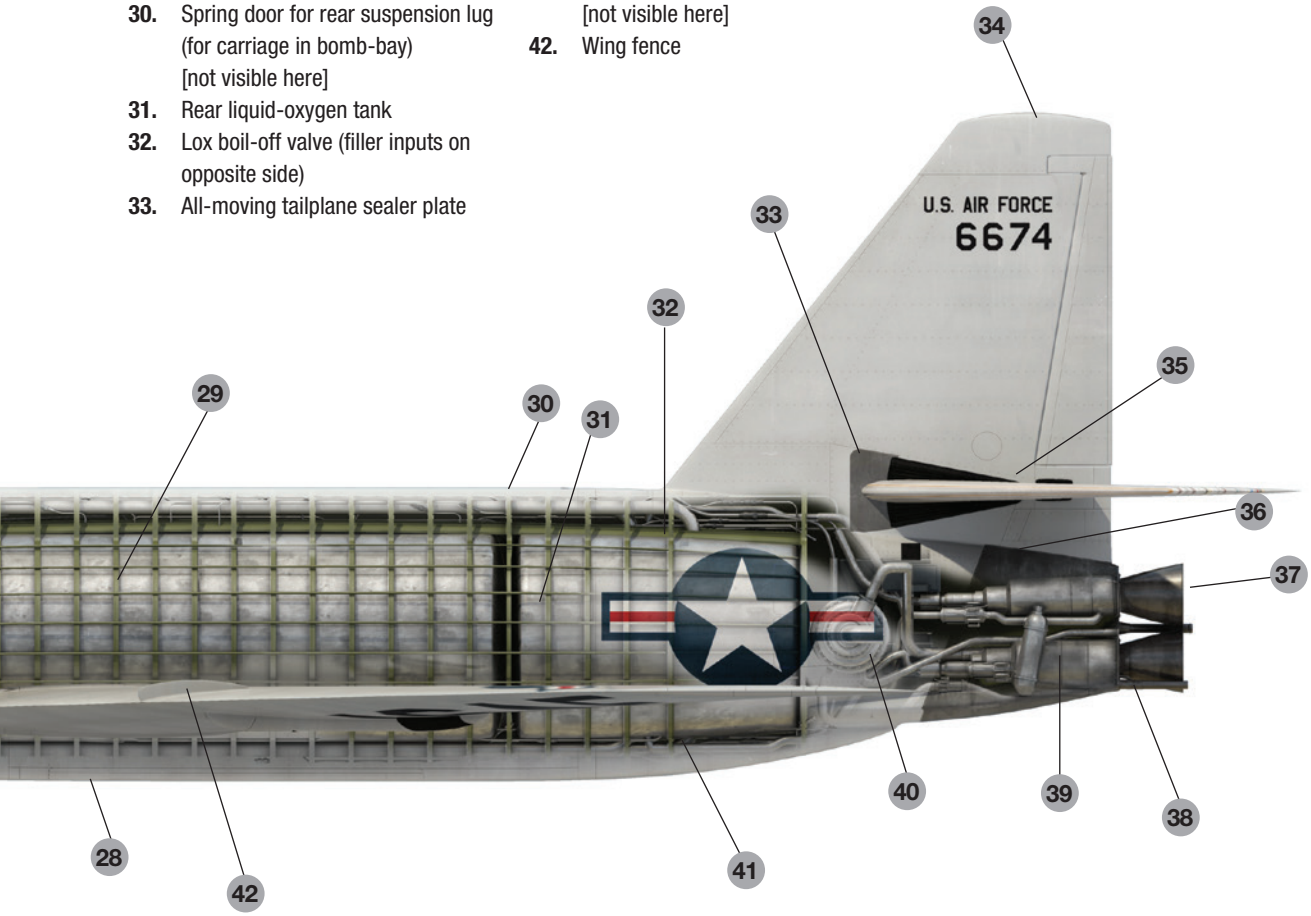
Bell were initially offered the Aerojet Rotojet using red fuming nitric oxide and aniline, which were as toxic and unstable as the substances used in the Me 163. RMI, instead, opted for the safer fuel combination

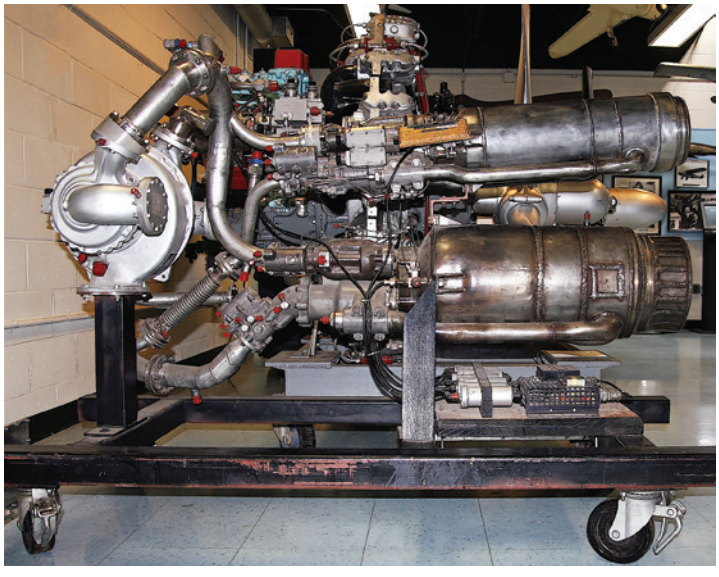
INSIDE THE BELL X-2

1. Air data probe
2. Pilot's suit pressurization nitrogen supply
3. Radar beacon
4. Front cockpit pressurization bulkhead
5. Rudder pedals
6. Control column
7. One-piece detachable canopy
8. Pilot's seat
9. Side console and glass wool insulation
10. Instrument recording camera
11. Rear cockpit pressurization bulkhead
12. Pilot's oxygen tanks
13. Nose landing gear with jettisonable cover
14. Windshield de-icing tank
15. Escape capsule main parachute stowage
16. Telemetry equipment and amplifiers in instrument bay
17. Capsule separation point, with jettison device and stabilizing eight-foot parachute
18. Radio tray and electrical relays
19. Spring door for forward suspension lug (for carriage in bomb-bay) [not visible here]
20. Lox duct
21. Lox boil-off valve



22. Forward lox tank
23. Bulkhead between tanks
24. Transformers and accelerometers
25. Battery compartment
26. Instrument compartment hatch
27. Cable and instrumentation duct fairing
28. Landing skid (retracted flush with lower fuselage)
29. Integral water/alcohol fuel tank
30. Spring door for rear suspension lug (for carriage in bomb-bay) [not visible here]
31. Rear liquid-oxygen tank
32. Lox boil-off valve (filler inputs on opposite side)
33. All-moving tailplane sealer plate
34. VHF antenna
35. Tailplane pivot
36. Rudder hydraulic lock
37. Rocket motor nozzles
38. Turbine exhaust duct
39. Curtiss-Wright XLR-25-CW-1/3 twin-chamber throttleable rocket motor
40. Turbopump
41. Turbopump gas storage bottle [not visible here]
42. Wing fence





The twin-chamber Curtiss-Wright XLR-25 that powered the X-2. (Daniel Berek)

that the Germans had employed for their V2 long-range guided ballistic missile. A diluted alcohol and liquid oxygen mixture gave slightly less thrust, but it would not combust spontaneously and it required an ignition system. The chemical components were also relatively cheap, available and non-corrosive.

The same propellants were chosen for Curtiss-Wright's XLR-25, mixed at a proportion of one part lox to 1.6 parts fuel. Their bulk occupied most of the X-2's fuselage interior between the instrumentation bay behind the cockpit and the engine bay at the tail, with two lox tanks containing 755.8 gallons and a single 860.3-gallon water/alcohol tank situated between them. Fuel comprised 13,800lb of the aircraft's 24,910lb gross weight. The fuel load was balanced by a sequencing system to maintain center of gravity during the rocket burn.

To save weight the three propellant tanks were integral with the fuselage, using the same K-Monel skin. For the early X-1s with their nitrogen pressurization system, it had been necessary to use heavy, welded steel propellant tanks, including 12 spherical tanks for the nitrogen supply, pressurized to 4,500lb. Despite being constructed from thick steel, these spheres tended to explode after about 700 "fills." Towards the end of the X-1 program two tanks had to be removed from the first example (46-062), which had already been consigned to a museum, in order to keep the remaining X-1 flying. Bell designers were anxious to avoid such heavy fuel tankage arrangements for the X-2, and they estimated a 20 percent weight saving by using the turbopump pressurization method.

The baffles that reduced fuel sloshing within the tanks – a possible source of aerodynamic instability – also acted as structural formers for the fuselage. Lightweight balsa wood discs were positioned between the tanks as reinforcement to enable thinner metal to be used for the end walls of each tank. The relatively small XLR-25 unit, weighing 483lb, and its turbopump were located at the rear end of the fuselage,

occupying a space that was only slightly longer then the width of the tailplane. The pump operated at around 325 horsepower as it moved the fuel through to the chambers at 600 gallons per minute.

Like the German V2, a regenerative cooling system circulated the cold fuel in a pipe network around the rear area of the motor and through the double walls of the rocket nozzles before it entered the combustion chambers. The one-third water component in the water/ethyl alcohol mix was principally to aid with cooling. A spark plug ignition coil for each chamber started the motor and the propellants were forced into the chambers by the lightweight aluminum turbopump when chamber pressure reached 50psi. The turbopump used steam generated by the same lox/alcohol fuel heated in the evaporating area of the engine to drive two centrifugal pumps for the propellants. A similar pump system had been used in the V2 by German designer Werner von Braun, who recognized that it would be a short-life component in its use for a missile. Developing it into a reliable, long-term device proved to be a lengthy process.

The turbopump was started up before launch of the X-2 by a compressed nitrogen supply carried on the EB-50 aircraft, and it then ran at 12,000rpm. Nitrogen was also used for the initial pressurization of the propellant tanks, but when the motor was started pressurization of the main fuel tank was provided by the 15-inch diameter turbopump. The lox tank was pressurized after start-up by gaseous oxygen produced

The engine test stand at Edwards South Base in November 1955, with 46-674's rocket engine filling the area with ear-shattering noise. The lack of ear defenders among the attendant personnel is typical of the times. (AFFTC via T Panapolis)

X-2 46-674, with its leading-edge flaps deactivated, on August 6, 1956. The auxiliary under-wing whisker skids were removed before the April 25, 1956 flight, and recently promoted Lt Col Everest was able to bring the aircraft to a halt on landing with the standard 12in-wide fuselage skid without either wingtip touching the ground during a 4,150ft slide. After most flights the central skid was removed for buffing and burnishing before being re-plated. (Bell via Jean Tellier)

in a heat exchanger that used the same alcohol/water steam to turn lox to oxygen gas. A back-up system of pressurized nitrogen in tube bundles, similar to those in the early X-1s, was available to jettison the contents of the water/alcohol tank in an emergency. The lox tanks generated their own pressure for potential jettisoning as the lox itself was constantly boiling off.

This complex system was controlled pneumatically from the cockpit by a conventional throttle for the propellant flow, with a cut-off switch to close the main propellant valves to the engine in an emergency. The throttle was variable between 50 and 100 percent power, but mixture control for the propellants was automatic. Curtiss-Wright devised a very advanced electrical simulator to model the engine's behavior in various conditions and it used large test cells to run the two-chamber prototypes. There was even an attempt to make an accurate thrust meter, although this was abandoned in favor of mathematical calculations.

Despite all these innovative efforts, the complexity of this advanced motor brought serious delays in development to the point where, after three years in which the X-2 had no clear prospect of a working engine, the USAF contemplated cancelation. Doing so would also have signaled the end of the X-2 initiative as no viable alternative power source was available. Aircraft development was moving at a very rapid rate, with the Mach 6 X-15 already being conjectured towards the end of 1952 when the XLR-25 was still missing from the two almost completed X-2 airframes. A compromise proposal involved the installation of two of the proven XLR-11 motors (a compromise that

was replicated for the early X-15 flights too), but the XLR-25 engines finally began to appear. Nevertheless, the first powered flight was not made for another three years.

ESCAPE

Perhaps the most bizarre of Germany's late-war rocket plane ventures was the Bachem Ba 349 Natter. Made of wood, with a 12ft wingspan, this aircraft represented a desperate last-ditch effort to stem the tide of Allied bombers. It took off vertically from a dispersed site using solid-propellant booster rockets and a Walter rocket motor powered by the same T-Stoff and C-Stoff fuels as the Me 163. Climbing at 37,400ft per minute and over 620mph under autopilot, the tiny aircraft would be flown above the bombers. The pilot, wearing a high-altitude pressure suit reminiscent of a deep-sea diver's, then jettisoned the nose-cone to reveal the firing tubes for up to 33 R4M rocket projectiles, which he released as he dived back down through the bombers.

He then had to jettison the complete forward fuselage, leaving him briefly exposed to the elements until a ribbon parachute (a type later selected for the X-2) in the rear fuselage deployed. Having already released his own harness, he would then fall forward out of his seat and descend beneath his own parachute. The rocket motor would also theoretically survive for re-use, lowered by parachute with the rear fuselage, but the landing impact often detonated residual fuel in the system, destroying the remains of the Natter.

American designers were aware that the Natter and He 176 rocket fighters and the M.52 used the idea of an ejectable pilot capsule to save the weight of ejection seats, which were, in any case, still being developed. While the X-1 had no plausible means of escape for the pilot, the D-558 used an escape capsule comprising the entire nose, with quick-disconnect devices for the control and electrical lines. It was a little-used concept that would reappear successfully in a modified form a few years later with the General Dynamics F-111, and it was also designed into Bell's X-2. The company undertook a complex design procedure to supply the means of survival in an emergency at high Mach and altitudes, where extremely low temperatures and airless conditions ruled out any conventional methods of escape.

The principal design challenges were to find ways of separating the nose cleanly and instantly and then stabilizing it as it descended. Free-flight RM-2 rocket models were used by NACA to test the concept from September 1947. The instrumented models simulated nose separation, and a full-scale X-2 nose section was tested under Project Blossom III. Fitted to a captured V2 rocket, it was launched to 150,000ft and 3,000mph, accelerating at 6g. It separated and was partially stabilized by an eight-foot ribbon parachute and then lowered on a 64ft diameter parachute that opened at 29,000ft. Several parachute lines were cut, probably by the gyrating nose, causing an excessive rate of descent. The test also failed to give a realistic impression of the conditions the system might meet at lower altitudes under much greater dynamic pressure.

Maj Frank "Pete" Everest is seen here on August 11, 1955 with the distinctive "Indian Chief" helmet that was decorated for him by his groundcrew in recognition of his role as chief test pilot. Bell's X-1A had been destroyed just three days previously in an explosion similar to the chemical detonation that blew up X-2 46-675. Everest's final X-2 flight on July 23, 1956 saw him attain Mach 2.8706 – just short of his Mach 3 target. After that he announced that he had accomplished his mission at Edwards, saying "You can't stand still." He duly moved to a new appointment at the Armed Forces Staff College. (AFFTC via T. Panopalis)

Development proceeded despite these inconclusive results, and NACA explored the addition of retractable, 30in-long stabilizing fins. A better ribbon-type drogue parachute proved to be a lighter, cheaper solution for stabilization, but it was also decided to save more weight by deleting the large 64ft parachute used to lower the whole cone. Instead, once the nose-cone was stabilized and slowed to 120mph vertically, the pilot had to wait until it reached 10,000ft and then a buzzer, activated by a barometer, signaled that it was time for him to exit. He released the pressure-tight hatch and canopy over the cockpit and bailed out in the normal way, using his standard 28ft parachute. This proposal assumed that he had remained conscious after the initial shock of capsule separation, when the nose-cone was driven clear of the aircraft by four pyrotechnic pistons that gave it a 20g forward kick.

After early wind tunnel testing, a scale model of the nose section was parachuted from a Douglas C-47 aircraft and the 36in ribbon parachute appeared to stabilize it effectively in a 10,000ft descent. NACA and the USAF differed in their opinion of the scheme's safety, and NACA's judgment that it was essentially unsafe was tragically to be proven correct.

The escape process was made more difficult by the need to wear a restrictive David Clark partial pressure suit with its bulky helmet and face-piece. Pilots had briefly flown up to 50,000ft in test aircraft without protective pressurized flying suits. At 100,000ft the temperature was -51 degrees F and atmospheric pressure was 0.15psi, with oxygen at one-eightieth of its sea level density, leaving the pilot with zero chance of survival without an elaborate pressure suit. Descent to a lower altitude was therefore essential before leaving the comparative security of the cabin.

Pilots of the X-1 series had been given the David Clark S-1 or T-1 partial pressure suit (although Capt Chuck Yeager wore a normal flying suit for the first supersonic flight since he did not intend to go above

48,000ft), and a similar suit with a K-1 helmet was used for the X-2 flights. It was first proven operationally during "Pete" Everest's August 25, 1949 XS-1 flight to 69,000ft when a crack in the cockpit canopy caused sudden de-pressurization and the suit enabled him to recover and land safely. For the earlier supersonic flights up to 60,000ft Everest had donned two pairs of socks and gloves, winter underwear beneath the pressure suit and a heavy flying suit on top of that to survive in the unheated cockpit.

Climbing into the T-1 partial pressure suit was a complicated but vital prelude to a high-altitude flight, the pilot requiring the assistance of at least one technician. The suit itself was intended to be light and flexible compared with earlier models, and X-1 pilots reported that, when deflated, it was not much more restrictive on their movements than normal flying gear.

If the aircraft cabin suddenly lost pressure a valve in the suit's oxygen supply opened automatically and inflated bladder-like "capstan tubes" along the sleeves and legs and down the back. Together with cloth levers that tightened the suit, this provided pressure against the pilot's body that enabled it to withstand the considerable pressure caused by having oxygen from the same valve system, with two air connections, being forced into the lungs. The pilot then had to reverse his normal breathing cycle and put his effort into exhaling, as the inhaling was "force-fed." He was also theoretically allowed enough muscular movement either to control the aircraft while it descended to lower altitude or to bail out if all else failed.

The suit, specification MIL-Y-3280 supplied at a cost of $344.60, complete with two sets of underwear, also protected the pilot from extreme acceleration, using features of the G-4A g-suit. By 1949 the USAF made wearing the T-1 mandatory for all flights above 50,000ft. The suit also stopped the expansion and extreme temperature increase of the pilot's blood that would occur at 60,000ft.

Fire crewmen and technicians converge on 46-674 after its near-disastrous landing on August 5, 1954. The collapsed nose-gear, long main skid strut and broken whisker skid (under the dirt-covered wing) tell their own story. More captive flights were required following lengthy repairs, and the aircraft entered its ninth year since the signature of contracts still without having made a powered flight. (USAF via T Panapolis)

The pilot's K-1 helmet consisted of a rubber bladder-like inner layer that covered his head and sealed with a flap at the neck. It housed the communications headphones and microphone inside foam rubber inserts. Restraining wires prevented it from pushing upwards with the suit inflated, which would have choked the pilot. An outer fiberglass shell, initially a two-piece white structure, later one-piece and green, provided impact protection and limited the expansion of the inner pressure helmet when it ballooned up, filled with oxygen. Capstan tubes ran around the surface of the inner helmet to stop blood vessels in the pilot's head and neck expanding. This uncomfortable ensemble was completed by a removable plastic face-plate with built-in breathing valves that had to be attached to the front of the inner helmet.

This head-gear severely restricted the pilot's head movements and limited his field of vision. This was unfortunate but acceptable in the X-2, but not for fighter pilots who also had to use the K-1, and it was eventually replaced by the MA-1 with better visibility and greater ease of movement. Each suit was individually made for a pilot, and according to "Pete" Everest each one was "a portable torture chamber. When it did expand it was so tight that you burst a lot of the little capillaries under your skin tissue. You ended up looking like you had been in a fight with two or three wildcats, that's how badly the suit would scratch you." At 5ft 7in, Everest found the cockpit very cramped, although the taller Jean Ziegler, who joined the X-2 program in June 1952, must have had even more difficulty.

THE NACA PACK

The US Congress agreed to double NACA's 1947 budget to almost $44.5m for FY1948 in order to increase its success rate in supersonic ventures. Initially, this focused on the XS-1 and D-558-I, including NACA's acquisition of an XS-1, but it also funded wind tunnel and rocket-powered model tests. The second phase of this program was to include the XS-2 and D-558-II with swept wings and a third phase would extend to the XS-3 (built as the Douglas X-3 Stiletto) and the D-558-III, which never materialized. NACA saw the first two phases as a chance to explore speeds up to the supersonic level, while Phase 3 would cover supersonic research. Its cautious policies were soon under pressure from the USAAF and Bell, who envisaged a much more rapid rate of development. However, for NACA, the X-2 existed simply to collect data, and it followed the more ambitious program that Congress wanted and paid for.

From the outset the XS-2 had a cooled and pressurized instrumentation bay located behind the cockpit section which contained a comprehensive suite of measuring devices that led to the aircraft's Press alias, "the flying laboratory." An upper hinged shelf area housed the radio receiver and transmitter, two more shelves to the rear of the radio area contained telemetry equipment, accelerometers and galvanometers and a central compartment held a large basket. The latter slid out to access NACA's eight-channel telemeter and an oscillograph. Beneath them, in the lower fuselage, was a compartment for two aircraft batteries, inverters and strain gauge batteries.

Visible here are X-2 46-674's unusually thick aileron trailing edges, the sturdy sway braces in the EB-50 fuselage and the instrument compartment, which is still open awaiting some more NACA "black boxes" before a flight. (AFFTC History Office via Fred Johnsen)

Bell instrumentation technician Bob Rohrer and colleagues removing oscillographs from 46-674 after a flight. The black basket at the men's feet contained a NACA eight-channel telemeter, a power control magnetic amplifier and an oscillograph. The square open compartment to the left of the instrument bay housed the eight-foot stabilizing ribbon parachute for the escape capsule. Working in the Mojave Desert was clearly ideal for those who sought a well-bronzed torso. (Bob Rohrer courtesy of Carrie Rasberry)

The forward capsule section also had roll and yaw recorders, airspeed and altitude recorders and disconnect plugs for the capsule jettison process. Constant monitoring of the fuel system, pumps and rocket chamber provided information on their respective pressure situations to a NACA ground station through a 30-channel telemetry network. Other channels were devoted to recording data on the aircraft's acceleration and maneuvering velocities, while strain gauges measured aerodynamic forces on the control surfaces and bending forces on the wing. As

the program progressed into the upper speed ranges thermocouple instruments were added to measure skin temperature in several areas of the airframe. NACA also recorded cockpit information with a camera behind the pilot's head, focused on the instrument panel. Measurement was initiated automatically. In the X-1 the pilot had needed to switch on the 500lb instrument package at the start of his descent from the mother aircraft, but this task was sometimes overlooked, resulting in a wasted million dollar mission in NACA's opinion.

LOADING AND FUELING

The choice of a weight-saving skid undercarriage posed obvious problems for the X-2's mobility on the ground. Loading the aircraft aboard its "mother ship" was challenging enough, but clearly some means of maneuvering it into position beneath the EB-50A was required. A purpose-built six-wheel dolly was duly constructed in 1950 to transport the rocket plane or, with its hydraulic, castering wheel units retracted, to hold it in position for engine runs on the ground. Easing it beneath the EB-50A's bomb-bay was also a challenge as the X-2's tail-end was 11ft 9in tall even without the dolly. The problem had been solved for the X-1 by making a loading pit under the bomber and backing the rocket plane down a slope into the hollow, from which it was pulled up by heavy-duty straps.

Later in the X-1 program two massive 20-ton hydraulic rams were built that lifted the bomber's main landing wheels by six feet so that the X-2 dolly could approach from the rear, maneuvered by a team of lusty engineers, and the EB-50A would then be gently lowered onto it. The hydraulic lifts also allowed for a range of other experimental aircraft to be carried, although this function was better served by the successor to the EB-50s, the B-52 Stratofortress. This used an underwing pylon to carry the X-15 and a range of later types.

After the aircraft had skidded to a halt on landing, the dolly was towed out to it and inserted under the X-2, using its hydraulic wheel and cradle adjustment systems to position it correctly. Groundcrew might have had to raise the wingtip that was closest to the ground to assist the dolly's positioning procedure. The rocket plane was then lifted clear of the ground by the same hydraulic systems, secured and then towed tail-first to the maintenance area by a standard tractor.

The X-2 was positioned inside the EB-50's bomb-bay by two electrical hoists on the bomb-bay's "ceiling" that engaged two hooks on the rocket plane's upper fuselage that were normally covered by doors. The aircraft was then carefully raised, inch by inch, until it could fit into the arched sway braces that held it steady inside the bomb-bay – this procedure could take up to an hour to complete. The X-2 tailplane fitted into the cut-out in the bomber's rear fuselage and its wings were steadied by two long, adjustable braces that projected downwards beneath the EB-50A's wing. These were added after the first trial carriage flights showed that the X-2 tended to shift around a little in its shackles, Bell calculating that they transferred the aerodynamic drag on the X-2 to the EB-50. The vertical fin extended far into the EB-50's

Dwarfed by its carrier aircraft, the X-2 is very gradually lifted into position in the bomb-bay. The EB-50D, which provided carriage for the flights by 46-674, was usually flown by Maj Fitzhugh L. Fulton Jr and co-pilot Maj Charles C. Bock Jr. Fulton retired from NASA in 1986, having completed 15,000 flight hours on more than 200 types. Bock worked on a similar range of aircraft, flying 70 in all during 10,000 flight hours. (AFFTC via T. Panopalis)

belly, and the cut-out portion for the horizontal stabilizer allowed room for it to be tested before launch.

Once the X-2 was in position the propellant jettison rig suspended beneath the EB-50's rear fuselage was connected to the rocket plane's dump ports. The cockpit hatch was loaded separately, ready to be latched into place once the pilot was seated.

It then took several more hours to fill the X-2's propellant tanks through filler and top-up valves for the lox and fuel located on the right side of the aircraft's fuselage. Boil-off valves for the lox tanks were situated above the forward and rear tanks, and these were connected by hoses until aerial launch took place. Half of the lox would usually boil off during the slow, hour-long ascent to launch altitude, so continuous topping up from lox tanks in the EB-50 was necessary. Venting tubes for jettisoning lox and fuel, together with a turbine exhaust vent tube, extended aft from the X-2 along the EB-50's rear fuselage. Batteries had to be installed in the X-2 and bottles pressurized to supply the cabin pressurization, jettison and fuel dump systems. Launching was initiated electrically by switches in the cockpit or in the aft observer's position, controlled by a circuit breaker in the pilot's switch display. There was also an emergency back-up mechanical release.

The first of the two X-2s to fly was actually the second to be completed. Lacking a workable rocket motor, Bell elected to hold the first aircraft (46-674) ready for installation of the XLR-25 when it finally arrived, and send the second (46-675) to Edwards AFB to carry out the initial glide flights. This procedure had also been followed for the X-1, with a series of unpowered drops being made with ballast in place of fuel and the motor to prove the aircraft's basic handling characteristics.

The second X-2 was rolled out on November 11, 1950 for eight months of intensive static testing. By July 1951 it was ready for a series of captive flights beneath EB-50A 46-011 from Bell's plant at Wheatfield, New York. In May 1952 the pair made the long flight to Edwards AFB to begin gliding trials. At that time the XLR-25 was still far from reliable, held up by ignition problems that caused such explosive reactions in its main 10,000lb thrust chamber that Wright Field considered replacing it with a second 5,000lb chamber. The temporary replacement of the motor with two XLR-11s was also reconsidered. The captive flights allowed opportunities to check the effective carriage of the X-2 airframe and make sure that the pilot's entry to the rocket plane could be made safely.

CHAPTER FOUR

ALOFT AT LAST

Takeoff for the EB-50D pilot required minimum rotation due to the limited ground clearance of his supersonic burden. The pilot for all but three of the flights carrying the second X-2 was Maj Fitzhugh L. Fulton Jr, a veteran of the Berlin Airlift and the Korean War – during the latter he had flown 55 combat missions in a Douglas B-26 Invader. Fulton had previously participated in the B-29A flights for the X-1 program, and he went on to fly as project pilot for the supersonic Convair B-58A Hustler bomber, in which he set a record altitude of 85,360ft on September 18, 1962, winning the Harmon Trophy for that year. Later, Fulton flew the B-52 with the X-15 aboard, the North American XB-70 Valkyrie Mach 3 bomber and the Lockheed YF-12A. His career culminated in a period as pilot of the NASA Boeing 747 that was used to transport the Space Shuttle back to Florida.

Fulton's co-pilot for the X-2 flights was Maj Charles Bock Jr, who also flew the B-52/X-15 composite. He became operations officer for the Lockheed SR-71A and on December 23, 1974 he made the first flight in the Rockwell International B-1 as the company's chief pilot.

Aboard the EB-50D, the X-2 pilot usually sat in the bomber's "panoramic view" glass nose position in full flight gear until the aircraft had reached about 5,000ft. This was considered a far safer alternative to remaining in the X-2 from takeoff, as an accidental or emergency drop from lower altitude would not allow time for recovery and landing by the rocket plane. He then made his way back to the bomb-bay area and climbed down into the X-2 cockpit from a walkway that fitted along the side of the aircraft. He disconnected the portable oxygen supply bottle that he carried from the flight deck, connected himself to the

A series of unstable landings by the X-2 necessitated revised landing gear, including a shorter hydraulic strut for a wider main skid and the deletion of the "whisker" skids under the wings. (Bell via T. Panopalis)

Still showing its Bell "stork" nose-art, 48-096 takes X-2 46-674 aloft on a captive test flight. Aileron checks were done while the X-2 was suspended in the bomb-bay of the EB-50. Movement of its tailplane was also tested within its cut-out space in the fuselage. (USAF via T. Panopalis)

X-2 oxygen system and handed the portable bottle to a crewman. Later in the program the EB-50 had two gondola-like fairings that projected downwards around the X-2 cockpit area to provide more protection from the slipstream. Each fairing had two windows to illuminate the cockpit. When the EB-50 had reached 10,000ft the X-2 pilot would be strapped in, with his hatch located in the correct position using two handles, its framework and a strap.

At that altitude the members of the six-man EB-50 crew who were working around the X-2 would begin to suffer from a lack of oxygen, so they retreated to the nose section of the bomber or used portable oxygen supplies in an emergency. For the X-2 pilot there was another half-hour wait while the EB-50 reached its launch altitude of around 30,000ft and "drop" speed of 250mph. During this time he began to pressurize the propellant tanks, checking carefully that they had reached the required levels.

The three chase aircraft that would observe the flight would also have taken off to accompany it at close quarters. At various times they included a Lockheed T-33 Shooting Star with a cameraman in the rear seat, an F-100 Super Sabre and the two-seat TF-86F Sabre – the second of only two examples built by North American as a potential rival to the T-33 as a USAF trainer. Their task was to keep a close eye on the X-2 and its carrier before and during launch, watching, for example, for any unplanned propellant emissions. After the X-2 was dropped they would try to keep it in sight as it soared away from them and then re-unite with it as it returned for a landing. One pilot usually accompanied the landing closely, calling out the diminishing altitude at ten-foot intervals from a parallel position off the X-2's left wing, while the other pilots flew above and behind the aircraft. It was a routine that worked well throughout the NASA rocket plane era.

SUPERSONIC SIM

Bell's X-planes were responsible for a number of "firsts" in applied aeronautical technology, and one of the less obvious innovations was

the first use of computerized simulation in a flight test program. In 1953 NACA's Richard Day, a former Eighth Air Force B-17 Flying Fortress pilot working on control and stability issues for the X-2 program, assisted the Bell team in programming (through patch leads) the USAF's Goodyear L3 Electronic Differential Analyser (GEDA) at Edwards AFB. NACA had persuaded the USAF to purchase GEDA the previous year.

Advanced for the early 1950s and advertised as "500 times faster than a slide rule," this basic, wardrobe-sized analogue computer could work out the equations that simulated, in relatively simple form, the X-2's flight maneuvers up to Mach 2.4 and present them on a television screen. Day also provided a rudimentary control column so that pilots could simulate the X-2's flight characteristics at various speeds. GEDA was, in effect, the first modern flight simulator, and it came into use during the aircraft's flight test program. It could be used to develop a flight plan for specific missions at simulated speeds approaching Mach 2.4, the pilot running through the simulation and then trying to reproduce the same flight profile during a test flight. The relevant data would be recorded on the aircraft's NACA instrument package, the two sets of inputs and results then being compared.

GEDA supported the findings from NACA's wind tunnels about the aircraft's deteriorating stability as it neared Mach 3, and the likelihood of "adverse yaw" if ailerons were used to roll the aircraft at that speed, leading to an uncontrollable tumbling motion.

X-2 pilots, most of whom were given simulator instruction by Dick Day, found GEDA useful. Korean War ace Capt Iven C. Kincheloe, who flew the X-2 from July 1956, reported that GEDA provided "the

Bell instrumentation technician Robert A. Rohrer with 46-674. He worked for the company after leaving school, riveting the wings on wartime P-39 Airacobra fighters. Rohrer returned to Bell after wartime service on B-29s. He was subsequently part of the groundcrew for both the X-1A and X-2 and remained an X-plane enthusiast for the rest of his life. A high spot was an appearance as an extra in the William Holden film *Toward the Unknown*, which featured an X-2 mock-up manufactured by Bell. (Courtesy of Carrie Rasberry)

BELL X-2 46-675
Edwards AFB, California, October 19, 1952

This aircraft was the first of the pair of X-2s to fly, and it is depicted here with the center of gravity black calibration marks that were applied for its second glide flight, from Edwards AFB, on October 10, 1952. Its pilot, Maj "Pete" Everest, put the aircraft through some basic stall maneuvers and aileron turns as it glided down from 30,000ft.

most valuable assistance given during the program. Original computer inputs were derived with the aid of wind tunnel and rocket model tests, manufacturers' estimates and theoretical predictions available at the start of the program. The stability derivatives were modified after each flight until the simulator could duplicate the flying characteristics of the X-2. Before each flight the pilot who was to fly the X-2 was given time at the [GEDA] analogue simulator with varying values of the critical stability derivatives. At higher Mach numbers and higher altitudes these variations gave flyable, marginal and un-flyable conditions."

GEDA was used to give a profile for the 13th powered X-2 flight (and the 20th overall). It predicted that the pilot would experience a condition known as control reversal, in which ailerons had the opposite effect to the pilot's control input if he adopted too high an angle of attack at speeds above Mach 2.4, causing adverse yaw to set in. Tragically, exactly that situation would occur on Powered

Flight 13 in September 1956. Overshooting the landing strip at Mach 3.2, the pilot initiated a turn that exceeded the safe angle of attack and completely lost control of the aircraft through "inertia coupling" – when the weight of the aircraft's fuselage was too great for the stabilizing ability of its flying surfaces. The circumstances of that last, fatal X-2 mission could be simulated closely on GEDA for future reference, even though they could not save the pilot from the consequences of that situation.

GLIDING TO DISASTER

Bell's chief test pilot, Jean "Skip" Ziegler, was in the cockpit for the X-2's first captive flights, which were concluded early in 1952. He traveled to Edwards with 46-675 and waited for its initial check-out and two further captive flights to be completed on June 5 and 15 ahead of the first glide flight on June 27. His brief was to test the manual flying controls over a series of five flights, beginning with the ailerons and graduating to the all-moving tailplane, exploring low-speed and stall characteristics in the last two excursions. The ailerons had been given additional booster tabs on their trailing edges, but these were removed for the opening tests flights.

NACA's methodical, thorough test procedures had required the first X-1 to make 14 glide flights before the motor was fired up. As the X-2 was already running more than three years late, it was important to begin powered flights without further slippage.

When the carrier aircraft reached 5,000ft, Ziegler, a tall, softly spoken Texan, climbed into the X-2's restrictive cockpit, pulled on his flying helmet decorated with an ace of spades on the front and his name at the rear and began to prepare for flight. The attendant engineers latched the canopy so closely around his head that his helmet touched its sides. He had to adopt an uncomfortable position to get his feet on the rudder bar. Eventually, the Boeing bomber completed its long spiral ascent to 31,500ft. At 206mph the red release handle in the bomber's cockpit was pulled and the X-2, loaded with concrete ballast to simulate a half-load of propellants and a rocket engine, fell cleanly away. Its overall weight was half that of a fueled-up X-2. Ziegler let the speed decay to 210mph and glided the X-2 down to begin his landing approach. The flaps went down at around 180mph and he began a final approach from

"Skip" Ziegler and a group of clipboard-bearing Bell technicians inspect 46-675 for damage caused by a barely controlled landing after the first unpowered flight on June 27, 1952. Detaching the cockpit canopy was the first job for the groundcrew following a landing, after which it was simply placed on the desert floor. Lowering the canopy back into place, with the X-2 suspended in the EB-50, required two detachable handles. The pilot then locked it securely from the inside. (AFFTC via T. Panopalis)

Another view of the first landing on June 27, 1952 shows the effects of the collapsed nose-gear and the wingtips digging into the desert dirt. Ziegler remains in the cockpit, no doubt glad to have been uninjured. The leading-edge flaps (lowered on the right wing) were deleted later. (AFFTC via T. Panopalis)

1,000ft, contacting the dry lake surface from a very flat, tentative descent at 142mph.

The aircraft's behavior during the landing run was then experienced for the first time, and Ziegler was in for an unpleasant ride as the X-2 continued to make an uncontrollable pitching motion. The main skid dug a groove over an inch deep into the dried mud and silt and then the nose-wheel, hitting the ground with 3.8g acceleration, refused to caster, collapsing immediately when its support assembly and lock-down mechanism failed as the nose came down hard. Lacking brakes, Ziegler could only try to keep the pitching aircraft fairly straight.

He tried to use the ailerons to steady it but that only caused a roll to the left that resulted in the right wingtip hitting the dirt, breaking off its bumper. Corrective right aileron rolled it the other way and the left wingtip dug into the desert, slewing the X-2 to a halt after a 1,010ft slide. Ziegler stepped out unhurt and the flight was officially declared a success, but the X-2 required several months of repair work. In Ziegler's opinion the aircraft's flying characteristics were no more than "adequate." With hand-made aircraft like the X-2, there were very few off-the-shelf parts available, and Bell could not deliver the necessary ones until late July. They included a wider main skid to minimize the tendency to dig into the surface and two small retractable "whisker" skids mounted at mid-span under the wings to stop the wingtips from scraping the ground.

This arrangement gave a trouble-free flight and landing on October 10, 1952, for which the aircraft was given center-of-gravity calibration markings on its fuselage. With the landing gear problems seemingly solved, Bell felt confident in asking Maj Frank "Pete" Everest to fly the X-2 later that same day, indicating the start of handing over the aircraft to the USAF. Maj Chuck Yeager, who was due to leave Edwards AFB and take up a new posting at Kadena AB, Okinawa, was on hand to

Jean Leroy Ziegler

Born in the small town of Endeavor, Pennsylvania, on January 1, 1920, "Skip" Ziegler came from a family that farmed and ran a natural gas station. An early interest in aviation was engendered by his brother's acquisition of a Piper Cub, which "Skip" also learned to fly. He idolized Charles Lindbergh and enlisted in the USAAC in 1940 after graduating from Penn State University. In 1941 he flew many dangerous missions over the "Himalayan Hump," transporting refugees from Burma in a Douglas DC-3 and supporting the American Volunteer Group, better known as the "Flying Tigers." Ziegler then spent a year surveying air routes for the USAAF and Pan American Airways, before being discharged from the Army in October 1942.

He duly joined the Curtiss-Wright Corporation as a production test pilot in Buffalo, New York, flight testing the C-46 Commando transport, P-40 Warhawk fighter, SB2C Helldiver dive-bomber and the novel XP-55 Ascender fighter (a flying wing design with a pusher engine). In 1946 Ziegler was involved in setting up United Services Airlines, flying war-surplus C-46 Commando transports. Entering the 1947 Thompson Trophy Air race in an XP-40Q fighter, he was forced to bail out when the aircraft's engine caught fire.

Still recovering from a leg fracture sustained getting out of the burning Warhawk, he briefly joined Bell Aircraft Corporation in 1948 as a rocket engineer but left the following year to become an engineering pilot on the F-86 Sabre for North American Aviation. He tested the B-45 Tornado jet bomber, AJ-1 Savage naval bomber and T-28 Trojan trainer. Returning to Bell in October 1950, Ziegler took charge of the swing-wing X-5 program. After the two X-5s had been handed over to NACA and the USAF, he made the only free flight in the Bell X-1D before it was destroyed in a fuel explosion. He then transferred to the X-1A, completing six flights in 1953, before moving on to the X-2 project.

Test pilot Jean "Skip" Ziegler, who made the initial X-2 flights. (Author's collection)

provide advice. Everest had previous experience of the X-1B, so he, in turn, felt confident in putting the aircraft through some basic stall maneuvers and aileron turns as it glided down from 30,000ft. He found that the chosen tailplane setting gave an excessive nose-down angle of attack, requiring some heavy stick forces to maneuver the aircraft. One of the whisker skids did not extend but the shock of landing made it drop into position.

A few days later X-2 46-675 was prepared for another return flight to Wheatfield for installation of the first acceptable XLR-25 motor and turbopump. After extensive ground-testing, captive test flights were then needed to prove the propellant dumping process and the exhaust system for the turbopump. In an emergency it was vital to be able to dump the volatile fuel load very fast. Equally, the demanding procedure for topping up the lox tank and pressurizing the fuel system during EB-50A ascent had to be established reliably. Very careful monitoring of propellant tank temperatures and pressures was vital during this stage of the flight. Several captive flights were made in March 1953 with increasing amounts of propellants, starting with a 25 percent load.

On May 12, 1953 pilot Bill Leyshon and co-pilot David Howe flew the EB-50A, bearing the X-2 with a full load of propellants, out from Wheatfield over nearby Lake Ontario to test the lox top-up and jettison processes. In Scott Crossfield's opinion this location was chosen instead of Edwards AFB due to "Ziegler's dedicated zeal to get the program rolling." As the bomber cruised over the lake at 30,000ft and 200mph the rocket ship's lox tank was topped up and drained and the process was then repeated. The tank's vents were then closed, allowing pressurization with nitrogen to commence. "Skip" Ziegler was in the bomb-bay carefully monitoring the pressure gauges for the top-off of lox.

One of the chase pilots, flying a Republic F-47 Thunderbolt close to the EB-50A's left wing, suddenly noticed a massive red fireball develop below the bomber's belly, engulfing the X-2 and the lower area of the carrier aircraft. His view was interrupted as a huge shock-wave threw his aircraft into a violent left bank and blasted the EB-50A 100ft higher. He noticed a piece of the X-2's outer wing flying past 50ft from his aircraft – the rest of the rocket plane had totally disintegrated. Bell personnel at Edwards heard someone transmit, "We lost the beast," followed by the voice of the chase pilot asking the EB-50 crew if they had the bomber back under control. Its bomb-bay was filled with a gray mist and a cloud of burning fragments in a flash fire.

Ziegler disappeared among them and was never found. Frank Wolko, a 33-year-old observer who was monitoring the fueling from the rear of the EB-50A, apparently bailed out through a side door in the aft fuselage and his body was seen falling, but shock, injury or oxygen starvation may have prevented him from opening his parachute. He too disappeared without trace. Despite extensive searches (which have continued more than 60 years later), the only trace of the X-2 that was found was a bucket of balsa wood fragments, painted silver on one side. They were the remains of the reinforcement discs separating the propellant tanks.

The EB-50A was also mortally damaged, but Leyshon and Howe skillfully brought it home to Niagara Falls airport with its various umbilical lines to the X-2 dangling beneath it. Although the conflagration in its bomb-bay had been brief, there was also severe shrapnel damage to its landing flaps and engine nacelles. More seriously, a crack was found in its main spar, probably caused by the violent changes in altitude experienced after the explosion. It had risen by between 200ft and 750ft, and also made sudden negative g accelerations. The rocket-taxi days of EB-50A 46-011 were over since Bell considered repair to be uneconomical. Instead, EB-50D 48-096 was diverted from the X-1A/B program, its place being filled by JTB-29A 45-21800.

The loss of Jean Ziegler and 46-675 was a terrible blow to the X-2 program. It had already used six years and more than $6m without any tangible result, and it was largely the thought of how cancelation might impact on the development of technologies needed for the upcoming X-15 that kept the X-2 alive. Now, another year would pass in which the cause of the disaster was explored. Meanwhile,

The ill-fated EB-50A 46-011 with 46-675 uploaded. Although USAF technicians thought that repairs to the bomber could be made after its disastrous fourth flight with 46-675, Bell did not want the consequent delays and requested an alternative EB-50D (48-096). (Bell via T. Panopalis)

preventive modifications costing almost another $1m were made to the surviving X-2, 46-674. Priority was given to improving joints in the fuel lines, with welds or brazing in place of mechanical joints. Propellant lines were also moved away from the aft lox tank, while the steel nitrogen tube bundles were replaced following a recommendation by Col Jack Ridley at the Air Force Flight Test Center (AFFTC). The tanks themselves were resealed with a new type of adhesive membrane, and fume-sealing bulkheads were placed between the tanks, but Bell Corporation also began to investigate the possibilities of a new, more robust system to replace the nitrogen type.

Ventilation in the EB-50D bomb-bay was improved and Bell engineers constructed an XLR-25 static test unit that included the entire propulsion system in an effort to try and analyse the problems. The USAF's own investigation in June 1953 also focused on the possibility of fumes being ignited in the X-2 fuselage space, probably by a stray electrical charge. It recommended that the lox top-up process should be eliminated in flight. The report also sought to find common ground between the accident and similar mysterious explosions that had wrecked the third X-1 (and its EB-50D transporter) and the sole X-1D, jettisoned to its destruction after in-flight pressurization problems during its second captive flight.

In fact, the tragic loss of 46-675 threw the whole X-2 project into a maelstrom of dispute. While Curtiss-Wright, the somewhat reluctant manufacturers of the rocket motor, insisted that their XLR-25 could be improved sufficiently to deliver enough thrust for Mach 3.2 flight, NACA at Edwards was urging Bell to replace the engine altogether. It complained of consistent failure of key components and general unreliability in the six engines it had received for static testing, and sought alternatives, including the possibility of a battery of four motors delivering 5,000lb thrust each. In fact, there was no practical alternative, and NACA began to wonder if the second X-2 would ever fly with a motor at all.

Meanwhile NACA's Ames laboratory was recommending the rebuilding of parts of the surviving X-2 with new metals such as iron/nickel alloys and new construction techniques that would give improved aerodynamic heating resistance at speeds above Mach 3. NACA Ames also wanted a thinner wing and a new, more powerful engine. In effect, it planned a completely revised X-2 airframe that would have required massive extra funding. That money was already being directed to the X-15 project. Structural modifications were limited to a three-inch forward fuselage extension, with compensating ballast in the rear fuselage, and bowl-shaped wingtip skids, although these were removed after the first glide flight. It also had the full hydraulic control system that replaced the simple manual substitute for a fly-by-wire system.

Throughout 1954 Bell continued to ground-test the XLR-25. For much of the time it behaved better as continuous modifications were applied. However, when the full motor and fuel supply system was set up in Bell's test stand it continued to malfunction in evermore unexpected ways, and NACA still felt that it was inadequate for X-2 use. By November 1954, four years after the first X-2 had been rolled out and almost nine years since the signing of the contract, no powered flights had yet been made.

The actual solution to the mysterious explosions did not emerge for a further two years, and it took the loss of another Bell rocket plane, the X-1A on August 5, 1955, to provide the evidence. This aircraft also sustained a detonation during the lox topping-off procedure at 22,000ft. Among other serious internal damage, its lox tank was ruptured and the aircraft had to be dropped like a bomb onto the desert as its remaining fuel could not be jettisoned.

Finally, Bell engineer Wendell Moore came up with the link between all four losses. He noted that all the aircraft used gaskets made by the Ulmer Leather Belting Company that were impregnated with carnauba wax and tricresyl phosphate to help them seal doors in two of the aircraft's inner bulkheads. These were in general use in the 1950s. Moore was aware that lox would detonate violently if it contacted organic materials and was then subjected to impact. He simply placed a sample of Ulmer leather in liquid oxygen and then struck it with a small hammer. The surprisingly violent explosion convinced him that further examination of the X-1B, which was very similar to the X-1A, would be profitable.

Samples of tricresyl phosphate were found in an oily substance inside the lox tanks of all four aircraft, and it was clear that it could leak out of the leather and then solidify in the tank. In all the X-1 losses it was possible to determine a point at which a comparatively mild shock could cause detonation of the chemical, with disastrous results. In the case of the X-2, the trigger could have been a lox tank vent strut that had been noted as vibrating strongly during previous captive flights. Ulmer leather gaskets were removed from the three remaining Bell X-planes and replaced with items using Teflon, Flexitallic or lead. There were no further problems of this kind.

CHAPTER FIVE

TRIUMPH BEFORE TRAGEDY

The surviving X-2, 46-674, was completed at the beginning of 1953, but it remained powerless as the first available XLR-25 motor had gone into the first X-2 to emerge through the Bell factory door, the now destroyed 46-675. Despite NACA's continuing misgivings about the project, 46-674, later nicknamed "Starbuster" in the popular Press, was transported to Edwards AFB with a Bell engineering team on July 15, 1954. Fourteen months had elapsed since the loss of the first aircraft, while investigations and modifications to the second aircraft were carried out. Replacement EB-50D 48-096 had also been suitably modified during this period.

Further static tests were performed at Edwards, and the first glide flight took place on August 5 with Maj Frank "Pete" Everest aboard the X-2. The World War II fighter ace had offered to take over the program following Ziegler's death, although his busy schedule as Chief of Flight Test Operations at the AFFTC had regularly given him up to eight new aircraft to test each month. The task was a welcome one for him, although it required courage to take it on after the destruction of 46-675, which was still unexplained at the time. However, Edwards AFB was a favorite for adventurous pilots, as he explained. "Most Air Force assignments only lasted three or four years, but at Edwards you would stay there for about six. It was the heyday of flight testing, with all the different airplanes being developed. We all wanted to stay at Edwards as long as we could."

Lt Col Everest made the X-2's sixth supersonic flight on July 12, 1956 – the first with the extended rocket motor nozzles. Technicians inspect the aircraft after a successful landing, premature motor shut-down having limited his speed to Mach 1.5. Some wear is evident in the white resin-based paint applied just before this flight. (Bell via T. Panopalis)

A distant shot of Maj Everest bringing the second X-2 in at 170kts for its first glide-flight landing on August 5, 1954. The nose-wheel is skewed at 45 degrees and only one whisker skid has lowered. These problems, together with a nose-down landing attitude caused by the length of the main skid strut, resulted in an uncontrolled slide that came close to disaster. (USAF via Terry Panopalis)

Everest spent three weeks at the Bell factory studying the X-2 and its power system, thoroughly familiarizing himself with the cockpit. On August 5 he made his first flight in 46-674, without an engine or fuel, having been carried aloft by a USAF EB-50 crew led by Capt Fitzhugh Fulton – a cheaper option than using a Bell crew. The X-2 was dropped at 6.5 tons, which was half of its all-up weight, at 220mph from 30,000ft after a 30-minute "cold soak" to check the batteries and control system. Chuck Yeager flew chase for the flight, which gave Everest a chance to test the revised hydraulic controls, the flaps and landing gear. The flight reinforced his opinion that the X-2 had pleasing flying and control characteristics, although application of full landing flaps caused a dramatic reduction in speed and altitude. He tried to control the aircraft without flaps, but the rate of descent was much reduced so he settled for half-flaps.

As Everest approached the landing area at 220mph, Yeager reported that only the left "whisker" skid had extended and the nose-wheel appeared to be angled at about 45 degrees to the right. Everest was reassured by Bell that it would caster to a straight course on touchdown, but as the main skid made contact at 170mph an old problem re-emerged. The nose-wheel slammed down but remained angled at 45 degrees, causing the aircraft to veer sharply to the right, skidding along sideways and impossible to correct by using the rudder. It then yawed the other way and the left wingtip dug into the lake surface. Everest was alarmed to feel the aircraft then slide backwards, continuing to yaw each way until it finally came to rest in a huge cloud of dust, with powdered desert all over its right wing.

Everest was shaken but uninjured, and surprised that the X-2 had not cartwheeled over onto its back. Accurate data on the incident was unavailable as the instrument pack had not been activated. Damage to the airframe was surprisingly small, which was a tribute to its strong construction. Yet another delay in the program followed as the aircraft had to be returned to Wheatfield for more repairs to be effected to its wingtips, whisker skids, flaps and nose-wheel gear and updates made to

A close-up view of 46-674 from the rear seat of a T-33A chase aircraft. Calibration marks were applied to the fuselage of the aircraft for its unpowered flight in March 1955 when Maj Everest tested the propellant jettisoning process. His landing on March 8 went well until the aircraft ran over one of the oil-based strips marking out the runway and skidded out of control, breaking off the right whisker skid and damaging the wingtips. (AFFTC)

its instrumentation. The nose-wheel's castering radius was also reduced so that it would be more likely to run straight. Bell's intention to install the engine at the same time was frustrated by further delays at Curtiss-Wright. It was mid-January 1955 before 46-674 reappeared at Edwards for its second glide flight.

Another glide was attempted on March 8 – only the fifth flight in three years. Its main purpose was to test the lox topping-off and jettison processes. Everest arranged with Bell's "top-off man," Ernie Kreutinger, to establish the best ways of doing this before he dumped the lox and headed down to test the landing gear again. While the topping off went satisfactorily, "Pete" Everest discovered that the jettison procedure was, in his opinion, "inadequate and even dangerous." In an emergency that required engine shut-down the aircraft could not be landed safely with even half its fuel still aboard without pushing its landing speed close to 250mph and over-stressing the undercarriage. To jettison this load the

EB-50D 48-096 is towed out for another launch of X-2 46-674. Puffs of lox emerge from the "drain" pipes on both aircraft. About half of the liquid oxygen would boil off before launch altitude was reached. The minimal ground clearance of the cargo necessitated careful rotation on takeoff. (AFFTC via T. Panopalis)

The simplified landing gear, omitting the whisker skids, is extended as a "tufted" 46-674 heads for home. Although powered flights were relatively infrequent, the X-2 was constantly ground-tested and modified by a full-time crew. Eliminating fuel leaks, pressure drops and erratic engine behavior were daily priorities. Eleven full engine tests were conducted within three weeks during June 1956. Parts were frequently replaced or improved to increase safety. (Bell via T. Panopalis)

tanks were supposed to empty in a sequence that preserved the aircraft's center of gravity and got rid of the fuel fast. Tests showed that the process took too long at around ten minutes, and the tanks were not emptying evenly. Later modifications reduced this to two minutes by installing much wider vent pipes with an improved jettison sequence.

Everest still had to face the prospect of another barely controlled landing. He touched down at a slightly slower speed of 160mph, just above the stall, and all went well until the aircraft – painted now with calibration markings – crossed an oil-based runway boundary marking strip. Once again, the X-2 skidded to the left and right repeatedly until it finally came to rest in a cloud of dust, slewed across to the right at 90 degrees after a very uneven run with the whisker skids apparently exaggerating the rolling motion from left to right. The right whisker and nose-wheel broke off completely. The usual trio of attendant, dust-covered vehicles bearing technicians, closely followed by the base fire truck and ambulance, soon appeared, and Everest was surrounded by inquisitive personnel. Damage was minimal but the whisker skids had their ground contact pressure increased to 800psi to improve stability.

A month later Everest made another glide flight, finding that the leading-edge flaps caused buffeting when retracted, except for final approach. All flaps were retracted immediately after touchdown. Sadly, the familiar wild ride on landing was repeated. Everest had arranged for a metal "crash bar" to be installed at the base of the instrument panel for him to grab in case of an unstable ride, and it proved its worth on this occasion. Sitting so close to the ground, he was painfully aware of his proximity to disaster, and the extreme difficulty of escape if the X-2 did indeed turn over. There was no point in trying to control the violent slides, and the X-2 almost tipped over as it completed its journey at right angles to its intended path, with a shaken, angry pilot aboard. Everest refused to fly the X-2 again until the problem was overcome.

Yet another return to Wheatfield ensued, followed by more months of delay while Bell engineers struggled to find a solution. Following a series of conferences attended by experts from Bell, Edwards AFB and the Wright Field laboratories, and the creation of experimental test models, it was decided that the X-2's angle of attack on landing was the root cause of the problem. The original USAAF contract had required the X-2's unorthodox main undercarriage to have the same shock-absorbing capability as a standard fighter-type aircraft. This required a comparatively long oleo strut that gave the X-2 its sharp seven degrees nose-down angle on the ground.

Bell chief X-2 project engineer, Stanley Smith, had long maintained that the strut placed the center fuselage too high relative to the nose. This in turn caused instability and a tendency for the nose to slam down on landing, with consequent damage to the nose-wheel assembly. Based on his experience as a glider pilot (he was National Soaring Champion for 1933), Smith argued that the X-2 always tended to come down well above its stalling speed, so a shorter, less energy-absorbing hydraulic strut would suffice. He knew that gliders using skid or single-wheel landing gear were quite capable of controlled landing runs, and he also had experience of persistent nose-wheel undercarriage problems in his work with the XS-1. The strut's length was therefore reduced by a half to 15 inches and the aircraft's ground attitude was thereby reduced to three degrees, placing the main fuselage closer to the ground on landing.

As a further contribution to improved landings, the main skid was increased in width from 12 to 21 inches and flattened in profile to reduce the aircraft's tendency to roll during its landing run. The larger skid increased drag, however, and Bell allowed for a return to the 12in model if the other improvements cured the landing problem. A final adjustment was made by reducing the friction in the nose-gear leg so that the wheel could caster more easily.

Manpower and skillful adjustment of the castering trolley wheels were necessary to position the X-2 exactly under the EB-50's fuselage. "Mating" was preceded by the installation of batteries and instrumentation in the X-2, which would have been thoroughly ground-tested in the days before the flight. The aircraft was then fueled, and the lox top-off process had to begin almost immediately. On rare occasions towards the end of the program the aircraft were left "mated" overnight. The EB-50D is seen here "de-mating" from X-2 46-674, which it has just delivered to Edwards AFB for the first time on July 15, 1954. (AFFTC via T. Panopalis)

Frank Kendall Everest Jr

"Pete" Everest flew 13 of the X-2's 20 flights during his time at Edwards AFB from 1950 to 1956. Born in Fairmont, Virginia, on August 9, 1920, he saw his first aircraft at the age of ten and knew from that point on how he wanted to spend his life. In 1941 he took advantage of the civilian pilot training program while studying engineering at the University of Virginia, entering USAAC pilot training in 1941 in the Aviation Cadet Corps. Everest's first combat assignment was with the 314th FS/324th FG, which was equipped with P-40 Warhawks – he soon found them to be inferior to German fighters once in-theater. Flying from bases in Tunisia, he completed 94 missions and shot down two German Ju 52/3m tri-motor transports.

After a period as a P-40 instructor in Florida, Everest was posted to the 5th FG's 17th FS (as its commanding officer) at Chin Kiang, China, again flying Warhawks but this time on missions into Japanese-occupied areas. He had shot down four more enemy aircraft by the time his fighter was hit by small-arms fire on his 67th mission in May 1945. Everest was almost killed when his parachute became ensnared on the aircraft as he tried to bail out. As he attempted to re-enter the cockpit the parachute suddenly freed itself. He was taken prisoner upon reaching the ground and received callous treatment by the Japanese, surviving imminent beheading only by becoming a source of (deliberately erroneous) information on Allied aircraft.

In 1946 Everest was selected as one of three aviators from 800 applicants for a test pilot assignment at the Flight Test Division at Wright-Patterson and Muroc (later, Edwards) AFBs. He joined the Bell X-1 program and made ten flights, establishing an unofficial world altitude record of 72,000ft in August 1949. Everest narrowly escaped death when the X-1D, on its second flight, was severely damaged by an internal explosion while in the bomb-bay of its carrier EB-50A and had to be jettisoned immediately, allowing Everest only seconds to leap clear of its cockpit. He became head of the Flight Test Operations division at Edwards in September 1951, testing the Bell XP-59, Convair XF-92A delta and most of the Century Series fighters, among many other types. In October 1953 he set a world speed record of 755mph in the YF-100A Super Sabre, flying at an altitude of just 75ft.

Following his time as the X-2 pilot, Everest was awarded the Harmon and Octave Chanute Trophies in 1956 and attended the Armed Forces Staff College. He then commanded the 461st FS (part of the 36th FW) at Hahn AFB, West Germany, followed by a tour as Director of Operations with the 401st TFW from 1961 and then command of the 4453rd CCTW at McDill AFB, Florida. In June 1965 Everest took command of the 4520th CCTW at Nellis AFB as a brigadier general. His final assignment was as commander of the USAF's Aerospace Rescue and Recovery Service. "Pete" Everest died in October 2004, aged 84.

Lt Col Everest with his "Chief head-dress" flying helmet, just about fitting into the X-2's tiny cockpit for a publicity shot. (AFFTC)

While these changes were being made Bell also decided to install the first available XLR-25 and finally begin powered flights so that the aircraft could be handed over to NACA. As the project entered its tenth year without any useful results, the team was given a final deadline of December 31, 1955 or else the USAF would abandon the project altogether.

POWER ON

The modified X-2 returned to Edwards once again on July 21, 1955 for a series of four flights to complete the Bell contractor's stage of the aircraft's development. These would be followed by USAF and then NACA test flights. Bell wanted to test the rocket motor on the first flight, but Wright Field insisted that the revised undercarriage should

Maj Everest with 46-674 on October 25, 1955, when, under pressure to make the first X-2 powered flight or face project cancelation, he launched with the engine installed for the first time and enough propellant to make a short powered run. Nitrogen leakage forced him to convert the mission to a glide flight instead but at least he had the satisfaction of making an exemplary landing on the revised skid arrangement. (USAF via T. Panopalis)

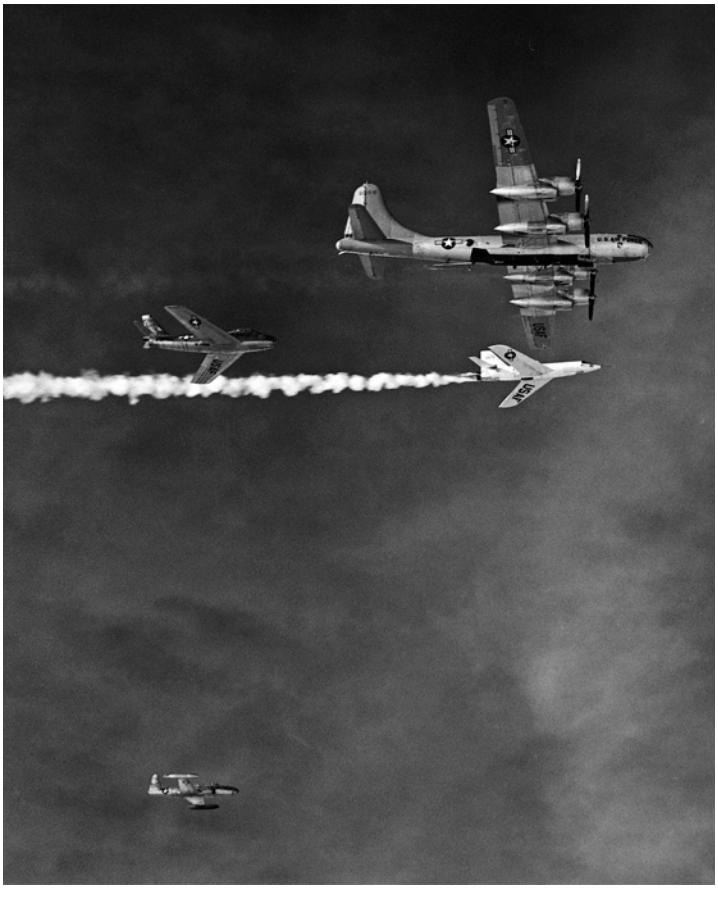
be tested first. Static tests actually took up most of the summer, and the first flight was not scheduled until October 25. On the ground the engine was still demonstrating a tendency to cut out unexpectedly. With such time pressure on them, the X-2 team decided that a powered flight would be the best option as it would at least generate some data on the XLR-25, even if the undercarriage broke on landing again. As Everest put it, "In the few weeks remaining out of the time allotted to us we had our last chance to redeem the work of years."

He was also aware that wind tunnel tests had shown that there were uncertainties about the aircraft's transonic stability, so caution was urged over the speed targets on the first flight. He need not have worried as it proved to be impossible to use the rocket engine on October 25. Everest had planned to use the smaller 5,000lb upper rocket chamber, making gentle maneuvers and letting the speed increase gradually towards Mach 1 while chase pilot Capt Stu Childs observed the X-2 very carefully from his F-100C and photographs were taken by accompanying F-86 and T-33 crewmen.

Soon after he had settled into the X-2's chilly cockpit for a half-hour of check-list work Everest noticed that there was a considerable leak in the nitrogen pressure. Bell engineers Bill Fleming and James Powell did their best to devise an answer, but it was clear that without the nitrogen to pressurize the fuel system the powered flight would have to be scrubbed. Shortly after being dropped by the mothership, Everest dumped all the propellants and settled for some basic maneuvers to test for airframe buffet, before he came in for a 175mph landing. To his relief the X-2 slid in a straight line and the nose dropped gently after about 500ft, deviating only slightly as the speed fell below 60mph. Nevertheless, Everest clung onto his crash bar, expecting a repeat of previous antics. Clearly the undercarriage problem, at least, had been resolved and the narrower 12in skid could be reinstated.

Further static tests and a captive flight appeared to sort out the nitrogen issue so another attempt at powered flight was made on November 18. Everest drove to work in the veteran, faded blue Model A Ford that was passed down from each senior test pilot to his successor. Yeager had driven it during his tenure and it still seemed a neat antithesis to the futuristic complexity of the pilot's next "vehicle" each day. Entering the Flight Test Center through a door surmounted by a placard stating that, "Through these portals pass the oldest and boldest pilots in the world," Everest prepared himself for what would be the first of the X-2's powered flights. Dropped at 255mph from 30,500ft in a shallow dive by the red-tailed EB-50A, the aircraft fell away more rapidly as it was fully fueled and weighed around 25,000lb. The national insignia on its rear fuselage was obscured by a band of frost caused by the cold internal lox tank.

Everest was concerned that he might not get the XLR-25 running before the aircraft stalled, but the 5,000lb chamber did ignite and he was able to dive to Mach 0.8, before pulling up in a climb to Mach 0.90. Capt Childs, shadowing him in his TF-86 Sabre, was close enough to detect some buffeting in the tailplane, so Everest cut the power to stop it and then restored power for a climb to 45,000ft up to Mach 0.95, with Childs still glued to his tail and noticing further slight buffeting around the horizontal stabilizer, which was not apparent to Everest. He repeated the stop-start process three times to try and ascertain where the buffeting began, but on the third occasion the motor cut out and would not re-start. Everest dumped the remaining propellants and headed for the landing strip, extending the main skid at 10,000ft. The right whisker skid did not extend and the nose-wheel was reportedly cocked at 45 degrees to the left. Fearing the worst and expecting a ground loop, Everest touched down at 200mph, the nose-wheel straightened itself and it became clear that the whisker skids were no longer required for a stable landing.



46-674's rocket motor ignites as it leaves the cavernous JB-50D bomb-bay, carefully monitored by the T-33A and TF-86F chase pilots and photographers. On the initial powered flights the thrust line of the 10,000lb rocket chamber, when fired up separately, could require full nose-up stick to keep the aircraft from diving. The rudder was usually locked and the flaps retracted at around Mach 0.85. Accurate in-flight measurement of motor thrust proved to be impossible, so mathematical calculations had to suffice. (Bell via T. Panopalis)

Inspection of the rear fuselage showed scorching and some damage to the vertical stabilizer and rudder from a small fire, started when fuel from the dump valve had been sucked back into the rear fuselage and ignited by the hot rocket chamber. Luckily,

X-2 46-674 approaching the landing strip with its three skids and nose-gear extended. Tufts have been applied to much of the fuselage and vertical tail to facilitate the study of transonic airflow. (NASA Dryden)

it had burned out before causing any severe damage to the tail surface controls. Even so, the X-2 had finally made a powered flight inside Wright Field's deadline and the program was duly reprieved on a $75,000 per month budget.

Repairs to the fire-damaged areas were made, together with modifications to the lox tank and propellant system following the loss of X-1A 48-1384 on August 8, 1955. Four months were needed for this work, and this, together with the annual winter flooding of the Rogers Dry Lake surface at Edwards AFB, delayed further flights. Continual tinkering with the complex fuel and pressurization systems continued during ground tests – a frequent activity between flights. Attempts at a powered flight on December 10 and 18 were abandoned due to fuel pressure and engine ignition difficulties, and the second powered flight was not possible until March 24, 1956, only a week before the planned handover of the aircraft to NACA. This time the smaller rocket chamber refused to light (necessitating further alterations to its starting circuit by Curtiss-Wright), but Everest used the 10,000lb thrust section to power the aircraft to Mach 0.91 and 45,000ft. His touchdown speed that day was 220mph and the aircraft "skipped" twice before settling at 185mph.

The X-2's third powered flight, on April 25, 1956, took it through the sonic "barrier" for the first time, despite initial difficulty in keeping the large rocket chamber running. Both rocket chambers eventually operated successfully and Everest was able to push it to Mach 1.4 and 50,000ft. The underwing whisker skids had been removed before this flight, but the X-2 landed evenly without them. Another successful supersonic flight on May 1 took the speed up to Mach 1.68 and an altitude of 55,000ft. There was a brief fire in the larger rocket chamber, but this was quickly extinguished when the chase pilot reported seeing a "large orange tongue of flame" – Everest turned the chamber off and

Tufts were applied to areas of the tail and fuselage of 46-674 for its first supersonic flight on April 25, 1956, when Everest reached Mach 1.4 during a 13.5-minute flight. Bell's technical report noted that, "The flight ended with a very satisfactory landing using only the 12in flat main skid, the auxiliary skids having been removed prior to the flight." (AFFTC via T. Panopalis)

then re-lit it. Poor engine combustion due to the presence of soap residue around the measuring gauge for a tank pressure transmitter curtailed a flight on May 11, the aircraft having reached Mach 1.8 in a dive from 60,000ft without difficulty prior to Everest aborting the sortie.

Clearly the persistent, long-running engine problems were gradually being defeated, although the X-2 was still far behind its original schedule and Everest was aware that skeptics were wondering if it would ever attain the Mach 3 target envisaged in its original design proposal 11 years previously. He agreed to lead the attack on the higher supersonic speeds while there was still an opportunity.

After an abandoned attempt on May 21, aborted after another engine start circuit fault, Everest made what he called "a balls-out flight

X-2 46-674, seen on April 25, 1956 en route to its first supersonic flight. Lt Col Everest reported no "jump" on the instruments or any appreciable trim change as he went supersonic. He did, however, comment on a noticeable nose-down pitch when only the 10,000lb thrust chamber was in use, and a nose-up pitch when the 5,000lb thrust chamber was operating alone. (USAF via T. Panopalis)

to see exactly what the X-2 could do in its present configuration." His early-morning takeoff on May 22 was preceded by the groundcrew giving the X-2 a full load of fuel from 0300hrs and calibrating the instruments. Chase pilots Capts Iven Kincheloe and "Mel" Apt, both of whom would also fly the X-2, were assigned F-86 Sabres together with Stu Childs for the mission, and Capt "Fitz" Fulton piloted the carrier aircraft.

The red "drop" handle was pulled at 30,500ft and Everest turned on the larger rocket chamber to level off, before adding the 5,000lb chamber and beginning a steep climb. In Everest's words, "Once they [rockets] are going you're hanging on and trying to fly a prescribed flight path to give you the best performance. This isn't easy to do because you have to climb and try to get above 60,000ft, then level off and perhaps dive a little to try and get the maximum Mach number out of the airplane. You do this until the propellants are exhausted and then you head home. Because you're still at 60,000ft you make a very gentle turn back because you don't want to lose control, and you don't have much control at that altitude."

He maintained the steep ascent, unable to keep the aircraft below 370mph despite using full aft stick, and began to level off at 55,000ft for a "push over" into a shallow dive from 60,000ft. In a burst of rocket power that trailed a 100ft flame and lasted for only around 2.25 minutes, the X-2 accelerated all the way to Mach 2.53 – by far the fastest speed achieved in manned flight at that time. The aircraft, leaving a white trail of steam from its turbopump, remained stable and controllable in Everest's expert hands, although aileron control was slightly reduced at the extremes of speed and altitude.

"You flew very, very gently and did the best you could while flying like a bat out of hell. Things happened so darned fast. If you got up to an altitude where you wanted to push over to get maximum speed

X-2 46-674 powers away from its carrier, with the aircraft's lower (10,000lb thrust) chamber operating. With both chambers functioning, the 6.35 tons of fuel would last for about three minutes, using 600 gallons per minute. Judicious use of the variable thrust could propel the X-2 for up to 330 miles. (NASA)

An over-the-shoulder view of 46-674 gliding back to Edwards AFB. The hinged doors of the cooled, pressurized instrument compartment are prominent. The choice of NACA instrumentation to be included in the X-2's payload was settled early in the program, but adapted as it progressed. The whole aircraft was essentially a flying laboratory, filled with equipment to monitor surface pressures and temperatures, control movements and forces, wing twist and bending, engine behavior, weights and performance. All the data was passed through a 30-channel telemetering system and a 36-channel oscillograph. NACA's instrumentation was carried in a removable basket for telemeters and oscillographs in the instrument compartment, or secured on a hinged radio tray, with another two shelves for additional "black boxes," a parachute section and a battery and inverter section. (Bell)

your altimeter indication was lagging behind, so you started your push over at about an indicated 5,000ft below where your real altitude was to compensate. You didn't want to push over too suddenly because you could 'unport' the [propellant] tanks where they feed into the rocket engine [causing negative g to stop the fuel flow]. If you 'unported' those and got air into the fuel system the rockets would shut down. That occurred several times."

On the return leg Everest was still some distance from Edwards and around ten miles above ground, and he would have to give his location to the chase pilots – who would have been left far behind in the double-sonic dash – so that they could pick him up visually. "After they locate you they fly close to you, looking you over to make sure no damage has been done to the airplane. You then set up your landing pattern and glide on in for a touchdown. All the flights were basically the same."

The May 22 flight proved that the X-2 team could now advance more confidently towards their ultimate speed objectives, and it also gave Everest the satisfaction of beating his personal speed record in the X-1B (Mach 2.3 on December 2, 1954) as well as Yeager's record speed of Mach 2.44 on December 12, 1953 – the fastest speed achieved by an X-1 series aircraft. To go faster still, with an engine consuming more than a ton of fuel per minute, would require longer rocket burn times

Capt Iven Kincheloe made the X-2's eighth and ninth supersonic flights during August 1956, and he is seen here blasting off on one of them. The first (on August 3) reached Mach 2.58, but on the second an electrical fault closed the XLR-25 motor down early, limiting his speed to Mach 1.5. A period of engine refurbishment followed, and on the next flight (September 7) he was able to set an unofficial altitude record of 126,200ft. (AFFTC via T. Panopalis)

and revised tactics to give a higher drop altitude or a steeper dive to gain speed. Modifications for improved performance would take time, and Everest knew that his six-year posting to Edwards was due to end in two months.

A new pilot had to be trained in readiness, and Korean War ace Capt Iven Kincheloe was given his initiation flight in the X-2 on May 25. He reached Mach 1.14 and found the aircraft easier to fly than he had expected, although the flight was cut short when the motor would not re-set after a shut-down. For this sortie the X-2's forward fuselage, areas of the wings and the vertical stabilizer had no paint. Kincheloe described it as "without a shadow of doubt, the greatest flight of my life."

Engine improvements were effected by shortening the fuel probes in the tanks to increase the amount of useable fuel and by lengthening the rocket exhaust nozzles. Curtiss-Wright made new nozzles that delivered their optimum expansion of the exhaust flow at between 40,000ft and 49,000ft rather than at low altitude. They were installed at Edwards in early July, ready for the next high-speed flight on the 12th of that month.

At the same time it was recognized that the X-2 could soon be approaching the "thermal thicket" of friction-generated high skin

BELL X-2 46-674
Edwards AFB, California, June 1956

Thin stripes of Tempilaq temperature-sensitive lacquer were applied to the X-2 to allow technicians to study the distribution of heat over the airframe at high supersonic speeds. It tended to run and discolor as higher temperatures were experienced, while the basic white resin-based paint bubbled and flaked off. Pilot “Pete” Everest had his name handwritten beneath the canopy of 46-674.

X-2 46-674 with its wings stripped to bare metal. The entire aircraft was re-finished in mid-May 1956 for exhibition on Armed Forces Day. As speeds increased and the aircraft hit Mach 2.47 at 57,000ft on May 22, it was found that the paint began to bubble and blister. Tests with a heat lamp showed that this occurred at around 338 degrees F, requiring time-consuming paint repairs. Regular refinishing became routine in the latter stages of the program. (AFFTC via T. Panopalis)

temperatures that had been one of its design objectives. Technicians applied thin stripes of Tempilaq temperature-sensitive lacquer, which has also been used in the testing of cars and firearms and, more recently, on the Rutan SpaceShipOne. The stripes were of different colors, each one with its own temperature threshold. When it reached that limit the paint would melt or change color, enabling a "map" of the airframe heating pattern in that area to be traced. On the X-2, stripes were applied on the control and flying surfaces

Frequent paint refinishing could also involve fresh stencilling of the chief test pilot's name below his "office window." The reduced size of many instruments on their small front panel made them difficult to read in conditions of severe buffeting and vibration or under high g forces. (Bob Rohrer courtesy of Carrie Rasberry)

Iven Carl Kincheloe

"Kinch" Kincheloe was born in Detroit, Michigan, on July 2, 1928, although he spent his childhood on a Michigan farm. He was flying solo by the age of 14, determined to be a pilot – an ambition increased by meeting Chuck Yeager and sitting in the X-1 cockpit while he was a USAF cadet in 1948. After graduation from Purdue University in 1949 Kincheloe was commissioned in the USAF, test-flew the F-86E Sabre at Edwards AFB and was sent to South Korea in 1951 to fly F-80s and then F-86s with the 25th FIS/51st FIW. Completing more than 130 combat missions, he was credited with five MiG-15s shot down, six damaged and four destroyed on the ground between January 6 and April 6, 1952.

After promotion to captain, Kincheloe spent the second half of 1952 as a gunnery instructor at Nellis AFB. While there he was selected to attend the Empire Test Pilots' School at RAE Farnborough, Hampshire. In 1954 he was sent to Edwards AFB, test-flying all the Century Series fighters before joining the X-2 program to replace Frank Everest. In this role he made the first-ever flight above 100,000ft, earning the popular title "America's No. 1 Spaceman." Kincheloe also exceeded 2,000mph during the same flight, on September 7, 1956. He was awarded the 1956 Mackay Trophy for this feat. Fellow test pilot Bob White recognized him as a man who was, "obviously on his way to the top."

After the closure of the X-2 program three weeks later, Kincheloe was selected as project pilot on the X-15 and would have continued into other advanced spacecraft projects. On July 26, 1958 he was tasked with ferrying an F-104A Starfighter from Edwards AFB to the Lockheed factory. The engine of Kincheloe's fighter failed shortly after takeoff and he unsuccessfully attempted to eject at low altitude using the Starfighter's problematic downward ejection seat. He rolled the aircraft and ejected upwards, only to fall into the fireball of the crashing Starfighter. Kincheloe AFB in Michigan was renamed in his honor in September 1959, and in 2011 he was inducted into the National Aviation Hall of Fame.

For Capt Kincheloe, a tall man, movement in the cockpit of the X-2 with the canopy closed was clearly very restricted. Nevertheless, he gave an eloquent account of the view at 120,000ft. "The light intensity within the cockpit and generally surrounding the aircraft appeared to me to be typically that of normal 40,000ft conditions. Up sun, the sky was blue-black in color and the sun appeared to be a very white spot. The sky conditions down sun were even darker in color. This dark condition existed through the horizon, where a dark gray band appeared very abruptly. Extremely clear visual observation of the ground within a 60-degree arc directly beneath the aircraft was noted." (AFFTC)

in various positions from the eighth powered flight onwards, and in some cases they melted together, producing a Jackson Pollock-like confusion of color.

No paint lasted long on the X-2, and it would usually return from a powered flight with large areas of its basic white resin paint-finish blistered and flaked away by heat, which occurred at temperatures above 338 degrees F. For some flights large areas of metal were sanded, smoothed and left bare, as there was no time to re-finish them before the next launch. The X-2 received a complete re-finish in white resin coating in mid-June 1956 after all the remaining paint and filler had been removed, and Tempilaq was applied in several locations a few days later.

The X-2's opportunities to investigate kinetic heating would prove to be very limited, and NACA felt that the same results could have been achieved more easily and safely by using rocket-powered test models.

CHAPTER SIX

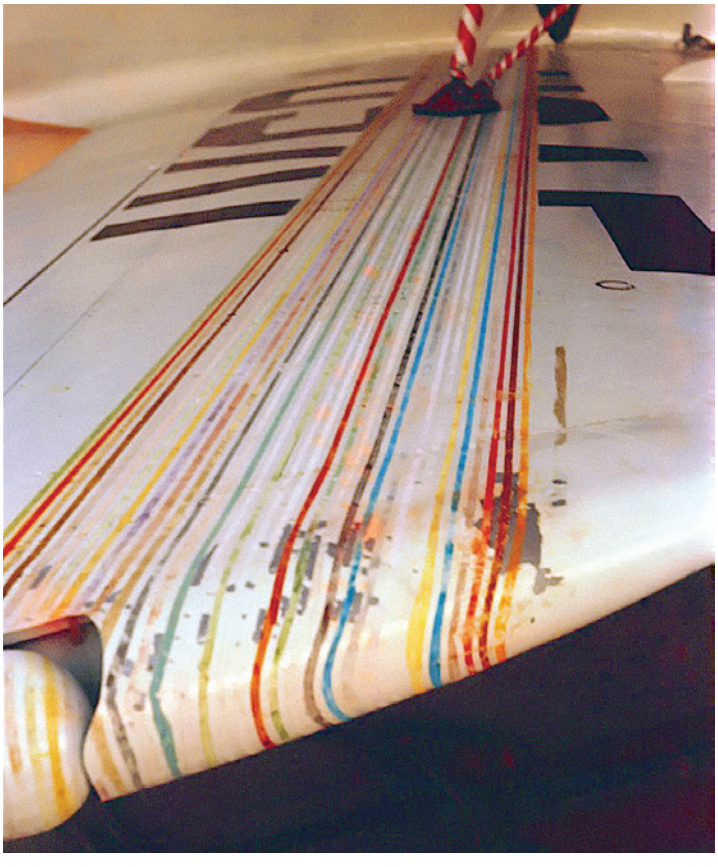
THINGS THAT ARE DANGEROUS

When asked what makes a great test pilot "Pete" Everest replied, "You have to love to fly, have a sense of adventure, be an excellent pilot and want to do things that are dangerous." Those qualities undoubtedly applied to all four of the pilots who flew the X-2 and to Scott Crossfield and Joe Walker who would have flown it for NACA if fate had not decreed otherwise. May 1956, with Lt Col Everest's Mach 2.3 record flight, marked the beginning of the true high-speed flight phase of the X-2 program. The handover date to NACA had been delayed but the USAF team was still under pressure of time and funding to wring out the aircraft and show that it had been a useful investment.

Everest made the first flight with the modified exhaust nozzles, revised fuel probes and Tempilaq stripes on July 12, but found that the motor cut out at Mach 1.5 when he began to push over for a faster dash. Negative g lifted the remaining fuel higher in the tanks and clear of the probes so that their sensors mistakenly determined that the tanks were empty. He made another attempt on July 23 – his last X-2 flight, and a bid to reach Mach 3 before his Edwards assignment ended. The technical purpose of the flight was to begin exploration of the so-called "heat barrier." A new 10,000lb chamber had been installed prior to the flight.

After an 0645hrs takeoff, the X-2 was dropped just as the EB-50D's No. 2 engine started to lose power after blowing a cylinder head. Everest

Perched on its central skid on Rogers Dry Lake in March 1956, with its whisker skids retracted, 46-674 has had the paint removed from its flying surfaces. They were repainted in April and May with white resin paint and filler. After Flight 9 that month, Lt Col Everest suggested that the whisker skids should be removed as the aircraft could be landed without them. (AFFTC via T. Panopalis)



These Tempilaq paint stripes, applied to the upper wing surface of 46-674, were photographed after the July 23, 1956 flight that saw Lt Col Everest reach Mach 2.87 – just short of his Mach 3 target – on what proved to be his last X-2 flight. Paint blistering is evident, and the red and white striped sway brace attached to the EB-50D's wing is seen at the top of the photograph. (Bob Rohrer courtesy of Carrie Rasberry)

accelerated away using both chambers at full power and climbing at 190ft per second until the propellants were exhausted after 2min 19sec – four seconds longer than any previous flight due to the shorter fuel probes. He then had a 12.5min glide home and completed a landing with the X-2 balanced on its 12in-wide skid. He had reached Mach 2.876 (1,900.34mph) at 68,937ft – just short of his target – and the Tempilaq melt patterns showed that temperatures above 500 degrees F had been experienced, with scorching along the wing leading edges and wingtips. Everest noted that the aircraft's longitudinal control had required gentle handling during the climb, and that control was

High-speed heat erosion of the basic resin finish is evident here, although the Tempilaq paint stripes remain largely intact. X-2s used a very strong, thin wing section with a convex circular arc profile and three degrees of dihedral. (Bob Rohrer courtesy of Carrie Rasberry)

The July 23 flight wrought havoc with the X-2's smart paintwork, which also had Tempilaq stripes applied. The green-tinted canopy reduced glare at high altitudes. (Bob Rohrer via Carrie Rasberry)

"marginal. If the pilot over-controlled or maneuvered the airplane too violently anything could happen." However, he was convinced that the X-2 could now attain Mach 3 and climb above 100,000ft.

Bell engineers immediately began to ready the aircraft for Kincheloe's first attempt at a high-altitude record. Static XLR-25 tests were carried out as usual and the whole system was repeatedly checked for persistent minor leaks, particularly in the lox system – a fairly common procedure between flights. In the event, the sorties on July 30 and 31 were captive flights due to oxygen leaks and a faulty throttle control. The EB-50D's engine had been repaired but the July 31 flight had to be abandoned when two of its other engines developed trouble. Kincheloe did not get a powered flight until August 3, when he reached Mach 2.57 at 85,000ft. The flight was a final check-out of the aircraft's handling characteristics before taking it to much higher altitude. Kincheloe

EB-50D 48-096 picked up an ARDC patch on its nose in the summer of 1956 when the USAF took over the program, replacing the Bell "stork" nose-art, together with larger *US AIR FORCE* fuselage titles and the AFFTC patch on its vertical stabilizer. The aircraft was also officially re-designated as a JB-50D. It is seen here on August 3, 1956 for Flight 9-56, which was performed to check the X-2's handling at 85,000ft. Despite loss of power on its No. 1 engine, the JB-50D was able to launch the 46-674 at 30,400ft after a "nose-over" to increase speed to 245mph. Kincheloe reached 87,750ft at Mach 2.58, experiencing mild Dutch roll and weaving motions from the aircraft at Mach 1.45, but otherwise finding that it flew well. (AFFTC via T. Panopalis)

X-2 46-674, secured for a flight in August 1956. Sealing "dams" are fitted around the aircraft's nose and the twin fairing boxes and the red protective cover is still in place on the nose boom. (AFFTC History Office via Fred Johnsen)

noted that its handling in the climb and 45 degrees left bank to turn for home (using full back stick) were excellent.

The aircraft's paintwork was repaired and extensive engine tests were made before another flight on August 8, when it reached Mach 1.5 at 70,000ft. However, Kincheloe was unable to keep to the set climb schedule in an attempt to avoid buffeting and the turbopump automatically shut down at 65,000ft. As Kincheloe, with his three attendant chase planes, returned to land his canopy fogged up on approach but a chase pilot guided him to a smooth landing.

There was a long period of refurbishment until September 7, during which the X-2 fuel system had further refurbishment, the EB-50D had extensive servicing and the whole project was taken over by the USAF from August 23. The only visible sign of new ownership was the addition of an Air Research and Development Command patch on the nose of the carrier aircraft, now re-designated JB-50D, in place of the Bell "stork" artwork. The September flight seemed doomed when the carrier aircraft's No. 1 engine began to smoke after an oil line broke. The X-2 was launched at a lower altitude of 29,000ft and 260mph and Kincheloe fired up both chambers two seconds later. In fact, the flight was outstanding, the aircraft setting an unofficial world altitude record of 126,000ft that beat the August 26, 1954 record of 90,440ft set by Maj Art Murray in the X-1A. It remained intact until Maj Bob White reached 136,500ft in an X-15 in August 1960.

The "drop" altitude was 29,000ft at 24,700lb loaded weight. The motor fired up at full thrust two seconds after launch when the X-2 had fallen for 500ft, and the aircraft was supersonic 18 seconds later. Kincheloe pulled the control column all the way back at Mach 1.25 and 56,000ft to assume the correct climb attitude of 45 degrees into the blue-black sky, although the aircraft actually climbed at 43 degrees. Finer adjustment was impossible under the headlong surge of the rockets' thrust. He had been provided with the assistance of a red grease-

Paint wear and partly melted Tempilaq stripes on 46-674 in a view that also shows the various vent pipes and the extended rocket motor nozzles. (Bob Rohrer via Carrie Rasberry)

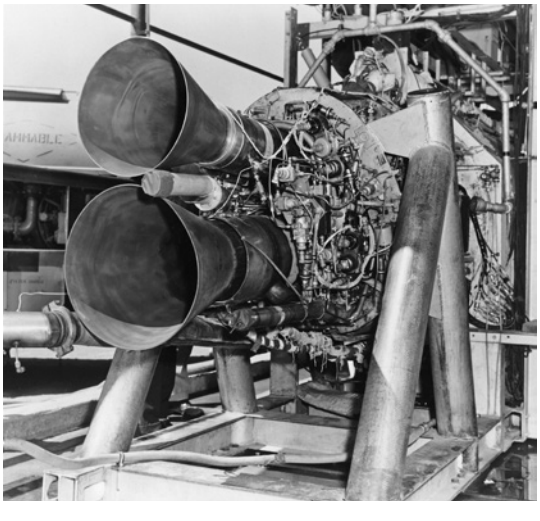
With both rocket chambers blasting out shock diamonds, 46-674 gathers speed to begin a long climb on one of its last flights in the summer of 1956. (AFFTC via T. Panopalis)

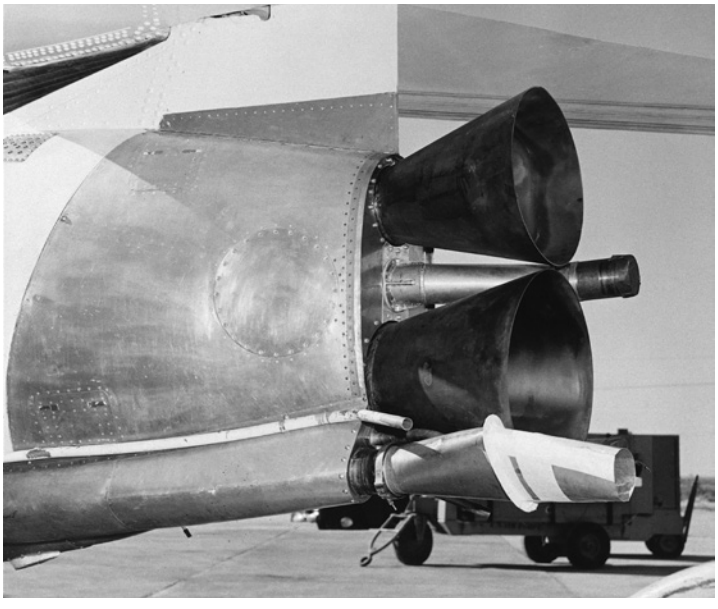
pencil line drawn on his canopy window which he had to align with the horizon to achieve roughly the correct angle of climb. Although it seemed a "lo-tech" answer, similar tricks were in common use by pilots of supersonic fighters in Vietnam ten years later to compensate for primitive bombsights.

With the motor blasting out 18,600lb of thrust, Kincheloe rode the X-2 at 1.45g and Mach 2 until engine shut-down. The tanks actually had another five seconds of fuel left at this point, and if the engine had not shut down after 2min 13sec when a "low fuel level" probe was uncovered as the remaining fuel moved to the side of its tank when the aircraft entered a 30 degrees bank, the X-2 would probably have reached 135,000ft. He began the push over, noting a considerable pitching motion that showed the X-2 to be longitudinally unstable in those conditions. The aircraft soared further up to 126,000ft, still traveling at Mach 1.67 (1,136mph), although Kincheloe's cockpit speed indicator showed only 62mph. Experiencing near weightlessness, he dived to Mach 2.6, with the aircraft continuing to reach un-commanded bank angles which would have led to uncontrollable rolling and yawing if he had attempted to correct it with the controls.

In Kincheloe's opinion the X-2 pull-out had to be completed at "an uncomfortably low altitude" due to the relatively ineffective flying controls. He uneventfully landed just over 16.5 minutes after leaving the JB-50D's shackles, with the TF-86F Sabre in close attendance. He later commented, "This height achievement was not only meaningful in that I had over 99.6 percent of the earth's atmosphere below me, but it is even more significant when one realizes that the X-2 was a ten-year-old design." The aircraft entered a 30-degree bank before engine shut-down and Kincheloe allowed it drop 40,000ft and travel 21 miles in making its 180-degree turn back towards Edwards, tightening the turn to a maximum of 3.5g as it entered denser atmosphere. He reported that, "No adverse aircraft characteristics were experienced throughout the entire climb. The aircraft was pleasant to fly throughout the flight and the achievement was anticipated."

An XLR-25 attached to an extremely robust test stand for ground runs. The nozzle extensions were fitted for the final six flights of 1956 after initial ground run tests Nos. 44 and 45 on July 7, 1956. At that time the engine also had thermocouples fitted near the fire detector in the engine compartment to record temperatures in that area and adjustments to the fuel tank pressurizing system to ensure that more of the residual fuel was used, increasing flight duration slightly. (AFFTC via T. Panopalis)





The X-2 with its XLR-25 re-installed and the nozzle extensions that were similar in purpose to those used on NASA's large, unmanned rocket vehicles. The aim was to maximize thrust at a time when higher speeds and altitudes were sought as a means of saving the program from cancelation. The large vent extending beyond and below the nozzles is the turbine exhaust duct. (AFFTC via T. Panopalis)

At the time, secrecy prevented the details of Kincheloe's achievement from receiving public recognition. It was also his final X-2 flight, as four subsequent launches had to be aborted and flown as captive missions, but it earned Kincheloe the nickname "America's No. 1 Spaceman" as he had passed the arbitrary altitude that defines the limit of Earth's atmosphere.

The 20th and final X-2 flight took place on September 27, 1956 after three aborted flights earlier in the month due to fuel system problems had used up valuable time. The USAF was due to hand over the aircraft to NACA by November 1, and after numerous delays there was a clear interest in pushing its performance as far as possible in the remaining days. NACA's main interest, under Joseph Vensel's direction, was in continued exploration of aerodynamic heating at supersonic speeds and transonic handling. Scott Crossfield, with wide experience of the D-558-II and X-1, was chosen as its project pilot, but he was persuaded away by North American Aviation to fly their hypersonic X-15. In any case, he had serious doubts about the X-2, calling it "jinxed." He had dismissed its original, costly electrical control system when he noticed that it made the control column move suddenly and violently in the pilot's hands. It was soon replaced by a cable system. When he inspected the aircraft he also noticed that fragile dry-cell batteries were being installed in it, and he deliberately dropped one on the work-bench to show how easily it would break under the strains of flight.

Joe Walker, who was to fly most of the X-1E missions and also 25 in the X-15, replaced Crossfield. Iven Kincheloe had been designated as the first USAF project pilot on the X-15, but he was killed before the aircraft's first flight. Sadly, Walker would never paint his usual "Little Joe" nickname on the X-2. He was only able to sit in the cockpit for a familiarization ground-run of the motor prior to a check-out flight that never happened.

Capt "Mel" Apt (left), Brig Gen Horace Hanes and Capt Iven Kincheloe with X-2 46-674. Brig Gen Hanes, a World War II veteran pilot who set the world's first supersonic speed record in an F-100C Super Sabre, also flew the X-1B. He was director of the AFFTC at Edwards AFB for four years from July 1953. (AFFTC)

THE COST OF MACH 3

Capt Milburn "Mel" Apt had been a USAF chase pilot on several X-2 flights and he was transferred to its cockpit ahead of Kincheloe's impending departure to North American Aviation for the X-15 program. Apt had received GEDA X-2 simulator training, sat in the aircraft for cockpit checks during ground runs and assisted with the X-2 launch panel operation during JB-50D flights. He was duly measured for a pressure suit and prepared for the aircraft's 13th powered flight on September 27 – his first flight in a rocket plane, and the one on which he would become the 13th test pilot to die during operations from Edwards AFB. The USAF insisted that Kincheloe was to be his chase pilot, causing a delay in the flight from September 25, as Kincheloe had to attend the premiere of the motion picture *Toward the Unknown*, a William Holden film loosely based on the X-2 venture.

"Mel" Apt boarded the JB-50D, piloted by "Fitz" Fulton, at 0715hrs and took up the usual seat in the bomber's glass nose area. He entered the bomb-bay at 7,000ft, put on his parachute and helmet and settled into the tiny X-2 cockpit. Kincheloe drew alongside in his F-86, accompanied by Capt Jim Carson in an F-100A and a photo aircraft. As the bomber headed east at 31,800ft, one hour after takeoff Apt

Capt Iven Kincheloe, dubbed "America's No. 1 Spaceman" after his September 7, 1956 record altitude flight, with Capt Milburn "Mel" Apt, who demonstrates the cramped cockpit conditions in the X-2. Apt joined the program in February 1956, and he flew several chase missions for flights by Kincheloe. Aged 32 at the time, he had become an acknowledged authority on inertia coupling – ironically, the dangerous phenomenon that caused his fatal crash on September 27, 1956. (AFFTC)

gave the "drop" signal and the X-2 fell away at 230mph. He ignited both chambers and climbed away at around 33 degrees, holding 350mph. Kincheloe advised him to pull back more on the stick as the X-2 shot ahead of his F-86, hitting Mach 2 at 50,000ft and Mach 2.2 at 70,000ft.

Apt had been told to follow the "optimum maximum energy flight path" – in other words, to push the X-2 harder than on any previous flight. Rather than waiting for motor burn-out, and still at full throttle, he began to push over into a shallow dive and the Mach meter kept moving upwards, exceeding Mach 3 or 2,000mph and peaking at Mach 3.196 at 67,000ft in a shallow dive. It was the logical result of using "maximum energy," and the fastest speed ever achieved by an aircraft.

The motor shut down automatically after 145 seconds, 15 seconds longer than anticipated, as the propellants ran out completely and Apt announced that he was beginning a turn back towards Edwards, but his message ended in a distorted, desperate shout. Kincheloe was unable to raise him on the radio and nothing could be seen of the X-2. Apt's unexpectedly high speed and long rocket burn had taken him further from base than planned, and he had to decide whether to keep to the original flight plan and decelerate steadily to make a safe turn for home. Apt's extra distance from base meant that he might not be able to glide all the way back unless he turned sooner, and at higher speed. Although the GEDA simulator had shown that this was possible, it had never been tried in reality, and other pilots thought it was risky in light of the X-2's longitudinal stability problems. Apt took the chance and initiated a 160-second left bank at Mach 3.

The aircraft's angle of attack increased as it slowed, decreasing its longitudinal stability and negating the effect of the ailerons as Apt tried to correct an increasing left bank angle and a yawing motion. The

NEXT PAGES

APT'S LAST FLIGHT

X-2 46-674 leaves the bomb-bay of JB-50D 48-096 for the last time on September 27, 1956 for its only Mach 3 flight. Following an 0715hrs takeoff, pilot Capt "Mel" Apt entered the cockpit as the bomber reached 7,000ft and technicians helped him to strap in. He performed pre-launch checks and checked that his lox tanks had been topped up from the JB-50D's supply. With Capt Iven Kincheloe's F-86 and Capt Jim Carson's F-100A chase planes in position, the bomber pilot turned eastward at 30,000ft and at 0849hrs the X-2 was released from its shackles. Only 2.87 minutes later, after a Mach 3.196 flight that reached 67,000ft, the little rocket plane was a shattered wreck on the desert floor and Apt had died in an unsuccessful attempt to use his escape capsule.

BELL Aircraft X-2

aircraft quickly entered a condition known as inertia coupling in which wild, uncontrollable tumbling through the air occurred. It entered a vertical supersonic spin followed by an inverted spin within a few seconds. Apt made two attempts at recovery, according to the recorded data, and then apparently decided that his only hope was to resort to the untried escape capsule. His built-in cockpit camera showed him being thrown about in the cockpit, with his helmet slamming against the canopy, probably dazing him.

Just over a minute from motor shut-down he was seen pulling the T-shaped ejection handle, explosive charges blowing the capsule clear of the gyrating X-2. The last images on his cockpit camera show him being forced back violently into the capsule, which continued to tumble wildly from 40,000ft, before the stabilizing parachute deployed. "Pete" Everest, who had always doubted the value of the capsule because it imposed such massive forces on the pilot during separation, assessed that Apt would have experienced forces of 14g at that moment, which would probably have rendered him unconscious. He did not emerge from the cockpit and deploy his own parachute as intended, although he did unbuckle his harness and eject the canopy at a very low altitude. The capsule's stabilizing parachute was never meant to lower the capsule and pilot safely to the ground, and it landed nose first at 120mph, crushing the forward section as far as the cockpit like a concertina. Apt's seat and helmet remained intact, but the impact killed him instantly. He was found, partly thrown out of the cockpit. The Edwards fire truck, ambulances, cars and personnel in an H-21 Shawnee helicopter were soon on the scene to examine the crash site, but there was no hope for the last X-2 pilot.

The rest of the airframe glided, stalled and glided again, landing in the desert about 35 miles from Edwards AFB and breaking into three sections only three minutes after leaving the JB-50D. The extremely strong center section with the wings remained surprisingly intact, the fuel tanks were in one piece and parts of the tail section were almost intact. Thirty-six years later aviation archaeologists found a buried shock absorber that still contained

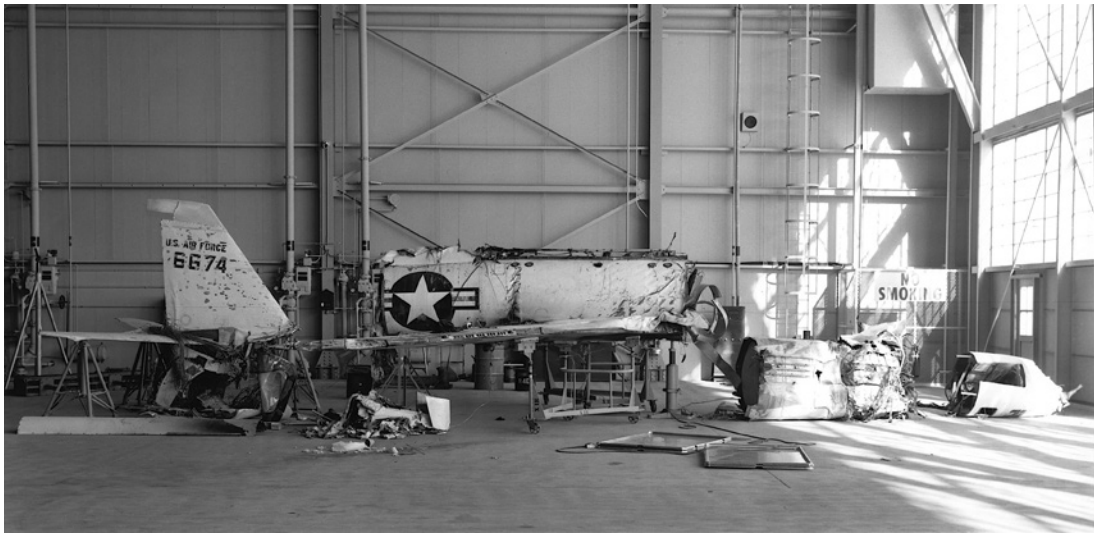
Capt "Mel" Apt with 46-674, near the tragic end of his 13-year USAF career that included two years as a test pilot. On one chase flight in December 1954 a Lockheed F-94C Starfire that he was accompanying caught fire and crash landed. The injured pilot, Richard Harer, was unable to get out of his cockpit as the fire blazed around him, so Capt Apt landed on the dry lake, ran across to the burning fighter and pulled the pilot out of danger. (AFFTC)

The remains of Apt's X-2, which broke into three large sections when it crashed east-northeast of Edwards AFB. The nose section was originally found some five miles from the main fuselage. (AFFTC)

hydraulic fluid. It seemed a possibility that Apt would have stood a better chance by riding the aircraft to a crash landing. Chuck Yeager had experienced similar roll-coupling problems during his last flight in the X-1A, but it had eventually assumed relatively stable flight in denser air and a lower speed. However, Yeager had experience of rocket plane flying, unlike "Mel" Apt, and he also knew that he had little chance of escape from the X-1A.

Prior to his death, Apt had reached a new record speed by making the first flight in excess of Mach 3. However, the circumstances of his loss immediately brought down the USAF's veil of secrecy, and no announcement was made until early October, when it was stated that Apt had flown faster than any other human. Everest's final flight on July 23, however, at "almost three times the speed of sound," was widely reported in early August 1956.

The crash brought the X-2 program to a violent end, although the relatively intact airframe was recovered and carefully examined in Bell's hangar at Edwards before being buried in the desert. For Crossfield, it also marked the end of a "grand era at Edwards. It closed out what might be called the first phase of the history of the experimental research airplane in the United States. All the old race-track enthusiasm was gone completely. Edwards became a place of hard work and routine." A rebuilding project for the X-2's remains had been considered, but was quickly rejected. NACA had already gained most of the transonic swept-wing data it needed from flights by the D-558-II Skyrocket,



The remains of 46-674 after careful examination in the NACA hangar. The forward fuselage and crushed capsule section are on the right. (AFFTC via T. Panopalis)

and production fighters like the F-100 Super Sabre were already flying faster than many of NACA's available aircraft. The slow pace of the X-2 project, blamed on lack of funds according to Everest, had delayed its speed and altitude record flights by several years.

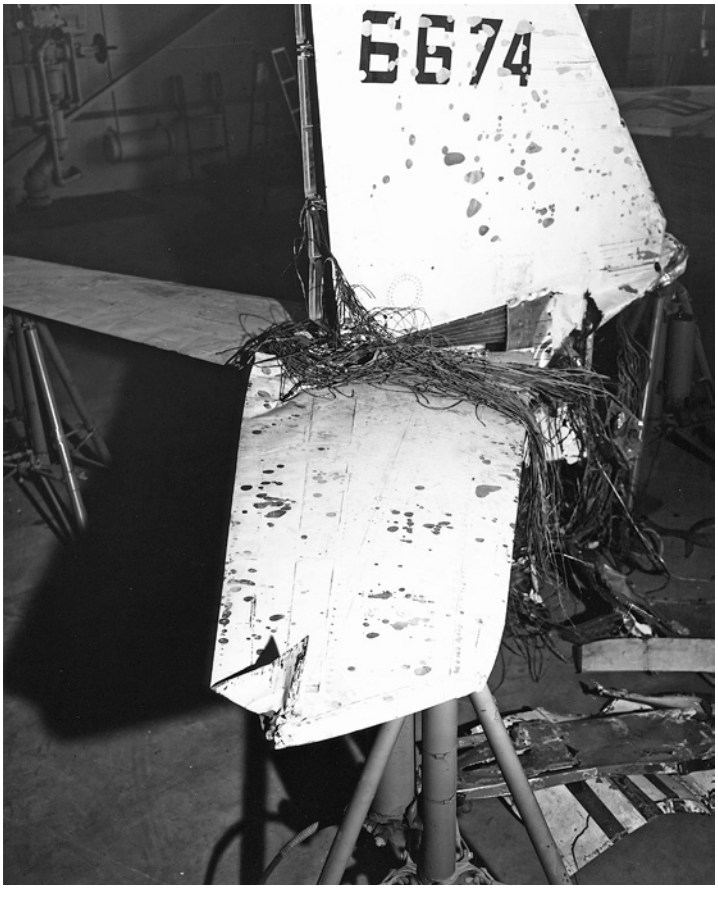
Apt's death caused much debate about the wisdom of allowing him to travel so much faster than any previous X-2 flight without even a familiarization hop in the aircraft. However, he had considerable experience of inertia coupling, having flown many F-100 research flights to explore the phenomenon. He had, however, been accustomed to slower aircraft than the X-2, and perhaps was not entirely aware of the extent to which the aircraft's flight instrumentation, particularly the altimeter, lagged behind the actual flight situation. Apt may well have read inaccurate dial displays concerning his height and speed when he initiated the turn. On Kincheloe's record altitude flight he reported that the altimeter was consistently showing a height 12,000ft lower than the radar tracking station was telling him. He had previously drawn attention to the "inadequate cockpit presentation for the pilot, low longitudinal control effectiveness and thrust misalignment."

NACA had warned that its wind tunnel data indicated that the X-2's directional stability was likely to deteriorate significantly as Mach increased, and advised the USAF to adopt the usual NACA approach of gradual, small steps, rather than sudden, major increases in Mach number. At the time, there was no data obtained from actual X-2 flights beyond Mach 2.4, and the Mach 3 attempt relied on mathematical forecasts. NACA's view was also that the USAF had been too keen to combine spectacular record speed and altitude flights in a compressed program before funds ran out and NACA took over. The USAF was assumed by commentators such as Ronald-Bel Stiffler, Center Historian for the AFFTC, to have taken a "calculated risk" in making that final flight, even though the X-2 was known to be capable of Mach 3 performance.

By November 1956 the criticism had become harsher. Wayne

Parrish, writing in the journal *American Aviation*, called the Defense Department's handling of the accident "probably the major public relations fiasco of 1956," noting that news of Kincheloe's altitude record flight, Everest's speed record and Apt's crash had all been held back until magazines like *Aviation Week* (which had previously been first to reveal Yeager's 1947 supersonic flight, despite a news embargo) had published leaked information about them. The *Los Angeles Times* commented on October 10 that the loss of the X-2 was reportedly "made relatively less important by the fact that the X-15 is being developed." To make matters worse still for the USAF, reporter Richard Tregaskis interviewed a former X-2 crew chief who pointed out that tests for the escape capsule to simulate the complex separation procedure could not really be effective, apart from those for the basic firing mechanism.

The harsh facts of test-flying at Edwards were generally unknown to the public, but Bob White noted that of the 39-man cadre of test pilots he flew with, nine were lost in one year. Sadly, the controversy surrounding the loss of White's close friend "Mel" Apt obscured the magnitude of the three X-2 pilots' achievements for many years and reduced the popular appreciation of the successes that the project achieved.



46-674's tail section on inspection stands. The "bellows" arrangement around the all-moving horizontal stabilizer pivot remained almost intact, but yards of instrumentation wiring have been displaced. Traces of unmelted Tempilaq paint could still be seen after the Mach 3.196 flight. (AFFTC via T. Panopalis)

CHAPTER SEVEN

AFTERTHOUGHTS

The surprisingly semi-intact wing and center fuselage of 46-674 in NACA's hangar at Edwards AFB on November 21, 1956. (AFFTC via T. Panopalis)

There were several proposals to extend the X-2's performance as early as January 1952, before its first flight. Robert J. Woods at Bell promoted the idea of hypersonic (Mach 5) flight to NACA at that time, drawing on the ideas of Walter Dornberger, former commander of the Peenemünde rocket test base in Nazi Germany and later a Bell consultant. He advocated a rocket-powered "ionosphere research plane" flying at altitudes up to 75 miles and with a rate of climb of 6,000ft per second. It would skip-glide in and out of the atmosphere and range across half the world. Another version of the X-2 proposed that year was fitted with JPL-4 solid-propellant booster rockets (from the MGM-29 Sergeant missile) to propel it to Mach 4.5 at 300,000ft and reaction controls to maintain high-altitude stability. Although NACA at Langley expressed some interest, the project never progressed.

In May 1955 Bell entered another X-2 derivative, the D-171, in the hypersonic aircraft design competition that was eventually won by the North American Aviation X-15. Bell's entry, which came third, used three XLR-81 rocket motors and resembled the X-2, with a straight trailing edge to the wings and tail, but it was to be launched from a Convair B-36 bomber and could reach 400,000ft at Mach 7. Even more ambitious outline proposals in 1952 included a version that would be air-launched from a larger rocket aircraft at Mach 3 and 150,000ft, reaching Mach 10 at an altitude of no less than one million feet.

Lacking realistic further development potential, the X-2 was to be the last of the early rocket X-planes. With the retirement of the X-1E in June 1958 there was a pause in rocket-plane flights until

the X-15's first flight in June 1959. The X-2 had been a protracted and problematic venture. It was repeatedly delayed by undercarriage failures, but its XLR-25 motor was the most constant problem. Leaking propellants, turbopump faults and frequent rocket ignition system difficulties meant numerous lost flights and a ten-year period in which it was difficult to detect any real outcome despite a $16m budget – far in excess of the original estimates. There were ongoing concerns about the aircraft's stability and control at high speeds and the viability of its pilot escape system. Kincheloe's high-altitude flight to 126,200ft had shown that a reaction control system was the only way to control an aircraft in conditions where the aerodynamic controls had no air to "bite" on. Reaction controls (tested in the X-1B) became a vital component in the design of the X-15. The latter's cockpit instrumentation (using an inertial guidance system), while still imperfect, gave the pilot better indications of his situation than the time-lagged displays in the X-2.

Although the aircraft had achieved both speed and altitude records in the accelerated final stages of its USAF program, there had been a tragic consequence. Walt Williams, with others at NACA, were concerned that the USAF had rushed this phase of the program with its last X-2 flight, losing a pilot and denying NACA the use of an aircraft which was at last becoming a useful research tool. As a result NACA was initially reluctant to involve the USAF in flying the X-15. However, many lessons were learned despite misfortune and disappointment. The X-2 had made a small but useful start on investigating aerodynamic heating, although much of this work was transferred to the surviving X-1B in September 1956. It had also contributed, albeit the hard way, to solving the challenges of Mach 3 flight at extreme altitudes. For NACA it had remained a useful bridging aircraft between the Mach 2 Skyrocket and X-1 series and the hypersonic X-15, despite the long delays.

Future aircraft would benefit from Bell's work with new metals for airframe structure and Curtiss-Wright's development of the first US-built throttleable rocket motor, as well as the ejectable pilot capsule and fly-by-wire controls. Cockpit instrument displays for later aircraft were also improved, and it became possible to evolve instruments such as gyro platforms and radio link equipment for high-Mach experimental aircraft. The program also emphasized the need for better-planned funding and tighter management, preferably under a single agency. In USAF historian Richard Hallion's opinion, "The X-2 story of delay and misuse" is a classic example of a program "that got out of hand. The rising costs of aeronautical research and development implicitly dictated that the days when a program like the X-2 would be *allowed* to continue were at an end."

It had been a bold, though extremely frustrating, venture at a time when little was known about flight beyond high subsonic speeds, and the structural and control problems that would ensue. Bell, NACA and the USAF had disagreements about the pace of the program, and its goals, but in that era of rapid and spectacular progress, a mixture of good engineering and some carefully calculated guesswork eventually achieved many of their objectives for the X-2.

OVERLEAF
Rarely seen in color, this famous photograph gives some idea of the massive team effort required to send one man (in this case, Capt Kincheloe, seen beside the X-2's cockpit) to the edge of space. The ambulance, fire truck recovery and radio relay and fueling vehicles were central to the convoy that arrived for each landing, and the T-33A, F-100A, TF-86F and H-19 helicopter were representative of the chase fleet that accompanied each flight. However, the most crucial supporters were the EB/JB-50D carrier aircraft and the scores of personnel. (USAF via T. Panopalis)

U.S. AIR FORCE
6674
BELL X2

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Front Cover
One of the main purposes of the X-2 was to investigate aerodynamic heating at speeds up to Mach 3, obtaining data to develop new high-temperature metal alloys for aircraft structures. Lt Col Frank "Pete" Everest's final flight in the X-2 on July 23, 1956 was one of these "heat" flights. It was the seventh supersonic flight for X-2 46-674. Parts of the airframe were painted with stripes of Tempilaq heat-sensitive paint which melted at pre-determined temperatures to record the heating effects of air friction at high Mach. A revised windshield was installed with tinted glass that could stand 1,000 degrees F. Everest climbed at full power to 68,205ft, reaching Mach 2.87 (1,900.34mph) – the fastest speed attained by a manned aircraft at that time. He noted the aircraft's very sensitive longitudinal control characteristics and the ease with which it could be over-controlled and become unstable, a main factor in the loss of the same aircraft two months later. As he leveled off after the rocket motor's 139-second burn time and re-entered denser atmosphere, heat damage occurred in several areas of the X-2's paintwork as it sustained temperatures in excess of 500 degrees F. Partial or total repainting of the aircraft was usually required after each high-speed flight. (Cover artwork by Adam Tooby)